AMEREN MISSOURI LABADIE ENERGY CENTER

LABADIE SULFUR REDUCTION PROJECT

METEOROLOGICAL MONITORING

STANDARD OPERATING PROCEDURE

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

LIST OF TABLES

LIST OF FORMS

1. INTRODUCTION

1.1 OVERVIEW OF METEOROLOGICAL MONITORING PROGRAM

This Standard Operating Procedure (SOP) provides a detailed description of quality control (QC) and quality assurance (QA) activities applicable to the installation, calibration, operation, and reporting of meteorological monitoring parameters.

It should be noted that this SOP is a companion document to the Labadie Sulfur Reduction Project Quality Assurance Project Plan (QAPP) which provides an overall description of the monitoring program, including the purpose, rationale and objectives of the project, as well as project organization, responsibilities, measurement quality objectives (MQOs), associated QA/QC elements, and data reporting requirements.

The proper use of this document and its references, including the manufacturers' instrument manuals, will help ensure that the MQOs established for the Labadie Sulfur Reduction Project are met. This in turn will ensure that relevant QA/QC requirements established for meteorological monitoring programs by the Missouri Department of Natural Resources (MDNR) and the U.S. EPA are satisfied; that the data collected are valid, accurate, precise, and are representative of the area of interest.

For the Labadie Sulfur Reduction Project, meteorological parameters will be continuously monitored. The parameters to be measured at the monitoring site are presented in Table 1-1. Tables 1-2 and 1-3 list equipment for the meteorological monitoring system. All meteorological parameters will be measured using Climatronics Corp. instrumentation. Data will be collected on a Campbell Scientific, Inc. CR1000 data acquisition system (the "data logger", or "DAS") on a continuous basis.

A summary of program measurement quality objectives (MQOs) is presented in Table 1-4.

The proper use of this document and its references, including the instrument manufacturers' user and engineering manuals, will help ensure that the monitoring data collected are valid, accurate, and precise, and are representative of the meteorological conditions in the area. The quality control (QC) and quality assurance (QA) program elements described herein are designed to maintain program data quality objectives with a data recovery rate of at least 90% per calendar quarter for each reported for meteorological measurement parameter. The monitoring program quality control and quality assurance elements and activities, including associated acceptability limits specified for system performance checks and preventive maintenance practices, are described in more detail in the following sections.

Table 1-1: Meteorological Parameters Monitored for the Labadie Sulfur Reduction Project

Meteorological Parameters Monitored	Measurement Frequency, Range and Units	Probe Level (meters)	Measurement Reporting Resolution	Instrument / Method
Northwest Site				
none				
Valley Site				
Horizontal Wind Speed	Continuous 0 to 125.0 mph	10	0.1mph	Cup Anemometer
Horizontal Wind Direction	Continuous 0 to 360^o	10	1^o	Vane
Sigma Theta (Standard Deviation of Wind Direction)	Continuous 0 to 104^o	10	1^o	Calculated
Vertical Wind Speed	Continuous ±25 mph	10	0.1mph	Propeller Anemometer
Sigma W (Standard Deviation of Vertical Component of WS)	Continuous 0 to 25 mph	10	0.1mph	Calculated
Ambient Air Temperature	Continuous -22° to +122°F	2	0.1^{o}F	Aspirated RTD
Air Temperature	Continuous -22° to +122°F	10	0.1^{o}F	Aspirated RTD
Temperature Difference	Continuous °F	10-2	0.1^{o}F	Calculated
Relative Humidity	Continuous 0 to 100%	2	1%	Aspirated Thin film polymer capacitor
Solar Radiation	Continuous 0-1,495 W/m^2	1	1 W/m^2	Thermopile-Type Detector
Barometric Pressure	Continuous 900 to 1100 mbar	1.5	1mb	Capacitive Transducer
Precipitation	Continuous 0 to unlimited inches	1.5	0.01 inches	Tipping bucket

Table 1-1: Meteorological Parameters Monitored for the Labadie Sulfur Reduction Project

Meteorological Parameters Monitored	Measurement Frequency, Range and Units	Probe Level (meters)	Measurement Reporting Resolution	Instrument / Method
Tall Tower Site				
Horizontal Wind Speed	Continuous 0 to 125.0 mph	65, 30	0.1mph	Cup Anemometer
Horizontal Wind Direction	Continuous 0 to 360^o	65, 30	1^o	Vane
Sigma Theta (Standard Deviation of Wind Direction)	Continuous 0 to 100^o	65, 30	1^o	Calculated
Vertical Wind Speed	Continuous ±25 mph	65, 30	0.1mph	Propeller Anemometer
Sigma W (Standard Deviation of Vertical Component of WS)	Continuous 0 to 25 mph	65, 30	0.1mph	Calculated
Ambient Air Temperature	Continuous -22° to +122°F	65, 30	0.1^{o}F	Aspirated RTD
Air Temperature	Continuous -22° to +122°F	65	0.1^{o}F	Aspirated RTD
Temperature Difference	Continuous °F	65-30	0.1^{o}F	Calculated

TABLE 1-2: MONITORING INSTRUMENTS AND PERFORMANCE SPECIFICATIONS	
Parameter/Equipment	**Performance Specification**
Wind Speed / Climatronics Model 100075 (F-460) 3-cup Anemometer	RANGE: 0.0 - 56 m/s THRESHOLD: 0.22 M/S DISTANCE CONSTANT: <1.5m (4.9 ft.) ACCURACY: ± 0.07 m/s or ± 1.0% of true air speed (whichever is greater) RESOLUTION: 0.1 m/s
Wind Direction / Climatronics Model 100076 (F-460) Wind Vane	RANGE: 0^o - 360^o THRESHOLD: 0.22 M/S DISTANCE CONSTANT: <1.0m (3.0 ft.) ACCURACY: ± 2^O DAMPING RATIO: >0.4 at 10° initial angle of attack RESOLUTION: 1^o
Vertical Wind Speed / Climatronics Model 102236 Vertical Component Propeller Anemometer	RANGE: ± 20 m/s (± 40 mph) THRESHOLD: 0.3 mph (0.14 m/s) DISTANCE CONSTANT: <1.0m (3.2 ft.) ACCURACY: ± 1.0% over range RESOLUTION: 0.1 m/s (0.22 mph)
Air Temperature / Climatronics Model 100093 Temperature Probe housed in Climatronics Model 100325 motor-aspirated radiation shield Dual-Element (linearized) solid-state thermistor (matched with Temperature Difference probe below).	RANGE: -30 to 50^oC ACCURACY: ±0.27°F (±0.15°C) over full range TIME CONSTANT: 3.6s LINEARITY: ±0.16°C ASPIRATION RATE: 10 ft/sec (3 m/s) at sensor location SHIELD EFFECTIVENESS: Under radiation intensities of 1,100 W/m² (1.6 cal/cm2/min) measurement errors due to radiation will not exceed 0.1°C
Temperature Difference / Climatronics Model 100093 Dual-Element Temperature Probe housed in Climatronics Model 100325 motor-aspirated radiation shield Dual-Element (linearized) solid-state thermistor (matched with Air Temperature probe above).	RANGE: -5.0^{o}C to +10.0^{o}C MAX ERROR PER DEGREE OF TEMPERATURE DIFFERENTIAL: ± 0.1^{o}C TIME CONSTANT: < 10 seconds in still air LINEARITY: ± 0.1^{o}C ASPIRATION RATE: 500 CFM SHIELD EFFECTIVENESS: Under radiation intensities of 1,100 W/m²(1.6 cal/cm2/min) measurement errors due to radiation will not exceed 0.1°C

TABLE 1-2: MONITORING INSTRUMENTS AND PERFORMANCE SPECIFICATIONS	
Parameter/Equipment	**Performance Specification**
Relative Humidity / Climatronics Model 102798 Thin-Film Capacitive Probe with Temperature Compensation housed in Climatronics Model 100325 motor-aspirated radiation shield Temperature compensation maintains accuracy even at 100% RH (saturation) conditions. Long Term Stability (+/-1% over 12 months)	RANGE: 0 to 100% ACCURACY: ± 2% TIME CONSTANT: < 10 sec. with 2 m/s aspiration REPEATABILITY: ± 0.3% OPERATING TEMPERATURE RANGE -50° to +50°C
Barometric Pressure / Climatronics Model 102663 Barometric Pressure Sensor Long Term Stability: calibration drift < ±1.0mb over 12 months.	RANGE: 600mb to 1,100mb (17.70 to 32.50'Hg) ACCURACY: < ±0.5mb over any 200mb range with offset correction RESOLUTION: 0.1 mb TIME CONSTANT: <10ms to reach 90% final output OPERATING TEMPERATURE RANGE -40° to +55°C
Precipitation / Climatronics Model 100097 Precipitation Gauge 8" funnel diameter maintains accuracy under heavy precipitation conditions. Windshield maintains accuracy under windy conditions.	RANGE: 0 to unlimited MAX ERROR ±1% for rain rates of 1 to 3 in/hr; ±3% for rain rates of 0 to 6 in/hr RESOLUTION: 0.01 inches
Solar Radiation / Eppley Model 8-48 (Black & White) Pyranometer Thermopile-Type Detector with Schott WG295 glass dome.	RANGE: 0 to 1,495 W/m^2 (0 to 2 Ly) SENSITIVITY: 11 µvolts per W/m^2 (approx.) RESPONSE TIME: 5 seconds (1/e signal) ACCURACY: ±3% LINEARITY: ±1% Across The Range RESOLUTION: 1 W/m^2 DOME TRANSPARENCY RANGE: 0.28 to 2.8 µm COSINE RESPONSE: ±2% from 0-70° zenith angle and ±5% from 70-80° zenith angle. TEMPERATURE DEPENDENCY: ±1.5% constancy from -20° C to +40°

TABLE 1-4: MEASUREMENT QUALITY OBJECTIVES

Monitoring Parameter	Minimum Sampling Frequency	Minimum Data Accuracy (Data Validation Limits) [1]	Minimum Data Precision	Minimum Data Completeness [2]
Wind Direction	1/sec	±5^{o} (azimuth & elevation)	Not Applicable	≥90% Per Quarter, with four consecutive quarters of 90% recovery for an acceptable one-year data base.
Horizontal Wind Speed	1/sec	±0.2 m/s	Not Applicable	
Vertical Wind Speed	1/sec	±0.2 m/s	Not Applicable	
Air Temperature	1/sec	±0.5^{o}C	Not Applicable	
Temperature Difference	1/sec	±0.1^{o}C	Not Applicable	
Relative Humidity	1/sec	±7%	Not Applicable	
Barometric Pressure	1/sec	±3mb	Not Applicable	
Precipitation	1/sec	±10%	Not Applicable	
Solar Radiation	1/sec	±5%	Not Applicable	

NOTES TO TABLE 1-4:

1. Validation Limit is the point at which affected data are invalidated if error is confirmed by a performance audit or calibration check. If limit is exceeded, affected data may be evaluated for possible correction of bias using linear regression analysis techniques of “as found” multi-point audit or “as found” calibration data. If, however, the “Begin” time of the excessive bias condition cannot be clearly and unambiguously identified in the data record, or if analysis of the “as found” test data indicate the bias is non-linear, the affected data must be invalidated back to most recent, previous acceptable Performance Audit or calibration check.

2. Completeness requirements for data averaging and data reporting periods are as follows:

Period	Minimum
1-hour (data-averaging only)	≥45 minutes of valid measurements obtained during a given hour
1-quarter	≥90% of total possible hourly values obtainable during that quarterly data reporting interval

2. MONITORING SYSTEM DESIGN AND INSTALLATION

This section addresses the criteria to be met for the installation of the meteorological equipment. Subsection 2.1 discusses the system design. Subsection 2.2 describes instrument siting and installation methodologies. Finally, Subsection 2.3 discusses instrument installation details.

2.1 SYSTEM DESIGN CRITERIA

The system equipment is designed to collect the greatest quantity of data possible with a high degree of precision and accuracy. The monitoring system is designed and installed in such a way as:

(1) To obtain a minimum 90% valid data collection efficiency for each parameter per calendar quarter;

(2) To conform to the guidance specified by the U.S. EPA in the Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurement Systems, EPA-454/B-08-002, March 2008;

(3) To meet the meteorological data quality criteria as specified in the Meteorological Monitoring Guidance for Regulatory Modeling Applications (EPA-454/R-99-005, revised February 2000 and all subsequent revisions)

(4) To ensure continued, reliable operation of each parameter system with respect to established performance criteria through a reasonable program of preventive maintenance and quality control activities.

All meteorological sensor signals will be integrated with a Campbell Scientific Model CR1000 data logger to provide necessary operating and reference voltages for each sensor and also acquire the analog measurement signals produced by each monitor. All signal connections between the data logger and sensors on the tower will incorporate commercial-grade surge protection circuitry to protect the data logger and downstream electronics from electrical surge damage.

The CR1000 data logger scans, digitizes and integrates each input measurement value at a rate of once per second. A 12-bit analog-to-digital (A/D) converter converts each analog input signal to a digital value. Digitized values are scaled to engineering units and/or processed using pre-defined algorithms in accordance with the data logger program instructions. The scaled and calculated values are stored for subsequent compilation of 1-minute, 5-minute, and hourly block averages. The data logger uses EPA-approved algorithms to calculate vector-averaged values for horizontal wind speed and wind direction as well as sigma theta and sigma w values. All calculated values are derived from instantaneous, sequential measurement values collected over the course of the averaging interval. The data logger also calculates the Δ-T between the upper and lower level temperature sensors, compiling and storing the averaged Δ-T values. The data logger similarly computes and store the total rainfall for each hour and for each 24-hour (midnight-to-midnight) interval. Total maximum data logger measurement error is a negligible ±0.2% of full scale range (FSR).

The CR1000 data logger stores programming instructions in non-volatile memory. Measurement data are stored in battery-protected SRAM and also in removable flash memory, thereby preventing data loss in the event of a power outage. The data logger will be equipped with sufficient flash memory to store approximately one year of data.

The 1-minute, 5-minute, and hourly block-averaged data stored by the data logger will be automatically uploaded on a daily basis from the data logger to a personal computer located in Enviroplan Consulting's Central Data Management Department in Wayne NJ by means of an on-site cellular telephone modem and automated data polling software.

The data logger will be configured so that any 1-minute, 5-minute, or hourly averaging interval that is missing the full number of possible scanned samples for that averaging interval will be automatically appended with an appropriate status flag. A minimum of 75% of all possible instantaneous values in a given averaging interval is needed to formulate a valid averaged data value. The data logger automatically excludes any missing or invalid data samples from final averaged values. Averages that contain less than 75% of total possible valid samples will be appended with other flags indicating an invalid average, depending on the cause of the missing or invalid samples (e.g., a power outage, instrument maintenance or calibration).

The Model CR1000 data logger will be mounted near the base of the tower in a NEMA-4X enclosure or in the monitoring shelter and include the following features:

- User-entered configuration parameters will be stored in non-volatile memory.

- In the event of a power outage at a site, the external backup battery will maintain the system clock, normal monitoring system operation and internal SRAM memory for a minimum of 30 days.

- A log of user-defined events will be maintained and available for download and review. The "Begin" and "End" times and date(s) will be identified in this log for each such event.

- A digital status input will be assigned to initialized data channels to "flag" invalid or suspect data. When the status input is activated, the incoming scanned data values will be excluded from the corresponding data averaging intervals. Site operating personnel will manually activate the status input to "flag" any data produced by a monitor undergoing manual calibration checks, maintenance or if the instrument is malfunctioning.

- User-configurable alarm firmware will append specific status flags to out-of-range data values, or data values for which the user-defined acceptable rate-of-change is exceeded.

- Full Ethernet communications capability will be supported for interrogating the DAS and downloading data either via a local terminal or printer, or remotely via the on-site modem and cellular telephone/internet service. All data logger functions will be accessible through local or remote communications. Communications with the data logger and configuration changes are restricted through built-in, multi-level password-protection.

- Data summary reports will be produced in an easy-to-read format that identifies the station name, date, time-averaging intervals and associated 1-minute, 5-minute, and hourly-averaged values in engineering units for each initialized data channel. The parameter name and measurement units are identified for each initialized data channel. Defined status flag symbols will be appended as appropriate to data values by the data reviewer to identify specific status condition(s).

The on-site data logger will provide a comprehensive data file for accurate and efficient reduction, processing and validation review. All data will be referenced to Local Standard Time, with status flags attached as appropriate to mark periods during which the monitors are undergoing calibration checks or maintenance.

1-minute data values for each parameter will be reviewed by the data technician using software that presents these data on a PC monitor as scaled, time-series plots. This allows QA-review of short-term data intervals equivalent to a strip chart record.

Monitoring project personnel can communicate with the installed data logger from remote locations by means of an IBM-compatible personal computer (PC) and internet connection and also locally by means of a portable laptop PC. Campbell Scientific LoggerNet PC-based software enables these communications, as well as automatic data polling, data processing and data reporting functions. The LoggerNet software will be used to monitor the station, transfer data to the central processor and develop the data reports. Sections 4.5.1 and 4.5.2 provide detailed information for establishing local and remote communication with the data logger.

Refer to Section 8 in this document for detailed information regarding data processing, validation and reporting procedures.

2.2 INSTRUMENT SITING AND INSTALLATION

The siting and installation of meteorological instruments are interrelated topics, so they are discussed together in this section. These installation and siting methodologies should be supplemented with the manufacturer's specific instructions in order to guarantee proper installation of the instruments. In addition, several secondary factors, such as accessibility and security, are taken into account during the siting process.

2.2.1 <u>Wind Speed and Wind Direction</u>

1) The wind instruments should be securely mounted on masts that will not twist, rotate, or sway.

2) Wind instruments should be top-mast mounted such that the tower structure is well below the instrument or alternatively mounted on a projecting, rigid boom such that the sensors are at a distance equal to twice the maximum diameter of the tower away from the nearest point on the tower. The boom should project into the prevailing winds.

3) All wind sensors should be aligned with respect to the vertical. Vertical alignment should be established with a good carpenter's or torpedo level at two points 90 degrees apart in the horizontal.

4) Horizontal wind direction sensors should be oriented to within ±2° of true north.

5) Preferably, all wind sensors should be sited away from any surrounding obstruction by a distance of 10 times the height of the obstruction. In cases where practical considerations regarding site selection (e.g., availability of land, utility services, access and security) preclude meeting the criteria, the sensors should be sited in an open area as far as possible from obstructions. A qualified meteorologist should evaluate the site location for suitability.

2.2.2 <u>Temperature</u>

1) The temperature (and Δ-T) sensors should be mounted over a plot of open level ground at least 9 meters in diameter. The ground surface beneath the instruments should not be concrete or asphalt, nor should the instruments be located any closer than 30 meters to a large paved area. The ground surface should be covered with short grass or, in areas where grass does not grow, natural earth.

2) The sensors should be shielded from direct solar radiation and adequately ventilated at a constant ventilation rate. The air intake of the radiation shield should be either pointed downward or laterally toward the north.

2.2.3 Relative Humidity

1) The relative humidity sensors should be mounted over a plot of open level ground at least 9 meters in diameter. The ground surface beneath the instruments should not be concrete or asphalt, nor should the instruments be located any closer than 30 meters to a large paved area. The ground surface should be covered with short grass or, in areas where grass does not grow, natural earth.

2) The sensors should be shielded from direct solar radiation and adequately ventilated at a constant ventilation rate. The air intake of the radiation shield should be either pointed downward or laterally toward the north.

2.2.4 Barometric Pressure

Barometric pressure sensors should be installed in a location that meets the following criteria:

1) Uniform, constant temperature (except if the instrument is not temperature-sensitive).

2) That has good general lighting but is shielded from direct sunshine.

3) Where it will have a solid, vertical mounting.

4) Where it will be protected against rough handling

2.2.5 Solar Radiation

1) A solar radiation sensor should, to the greatest extant practicable, be mounted above the plane of any nearby obstructions and at a height that permits ready access to the sensor for routine inspection. The sensor should be located such that shadows will not be cast on it and away from surfaces that could reflect light on it. The sensor should be mounted on a rigid platform with the light-sensing hemisphere facing upward in a level position.

2) The sensor should be mounted at a sufficient height above the underlying surface to prevent inadvertent contact and to prevent dirt and debris from collecting on the sensor.

2.2.6 Precipitation

1) The support, or base, of any gauge must be firmly anchored, preferably on a level surface so that the sides of the gauge are vertical and the collector is horizontal. The collector can be checked with a carpenter's level placed at two intersecting positions. The level of the bucket assembly on the tipping bucket gauge is also critical and should be checked along its length and width.

2) The gauge should be shielded from the wind but not placed in an area where there will be excessive turbulence caused by the shield. Obstructions to the wind should not be

closer than two to four times the obstruction height from the instrument. In open areas, a wind shield such as that specified by the NWS should be used.

3) The ground surface around the rain gauge may be natural vegetation or gravel. It should not be paved so as to avoid splashing the gauge. The gauge should be mounted a minimum of 30 cm (approximately 1 foot) above the ground higher if necessary so that it will not be covered by snow.

2.2.7 Meteorological Tower

1) Towers should be located in an open area representative of the area under study.

2) Towers should be of the open grid type of construction.

3) Towers must be installed strictly according to manufacturers' guidelines and specifications so as to provide a rigid and safe structure whereby the instruments may be sited at their specified levels. Proper consideration should be made for wind load and wind zone in specifying the design and type of tower to be utilized, as well as local and national safety codes and regulations. All towers installed by Enviroplan Consulting meet specific safety and code requirements appropriate to their use.

2.3 INSTALLATION DETAILS

2.3.1 Wind Speed Transmitter Installation

The Climatronics F460 Wind Speed Transmitter is mounted on the Climatronics P/N 100487 crossarm. Connections to the data logger are made via a signal cable terminating in an Amphenol connector provided on the crossarm. The crossarm is mounted on a vertical 1 1/4 inch pipe.

The sensor mounts on the pre-wired F460 crossarm by matching the keyed electrical connector and the notch on the lower part of the sensor body to the corresponding socket and keyed alignment pin on the crossarm. Secure the sensor by lightly tightening the two set screws located at the base of the sensor. The cup set attaches to the sensor by matching the groove in the cup assembly hub to the shaft hub and lightly tightening the set screws.

The Climatronics 102236 Vertical Component Anemometer is mounted on the Climatronics P/N 102234 mount which allows mounting to the vertical 1 ¼ inch mast. The sensor’s connector screws into the mount and the sensor is secured by turning the connector until it bottoms. Applying some silicone grease on the connector threads will facilitate disassembly should it become necessary. Install the propeller so that the propeller serial number faces away from the sensor.

2.3.2 Wind Direction Transmitter Installation

The F460 Wind Direction Transmitter is also mounted on the P/N 100487 crossarm. Signal connections to the data logger are made through the same signal cable connector as is used for the wind speed sensor. Mounting of the sensor is identical to the wind speed procedure, including mating of a keyed electrical connector and notch in the lower portion of the sensor with the corresponding keyed socket and alignment pin on the crossarm. The keyed sensor/crossarm mounting system ensures accurate generation of angular wind direction data, provided that the crossarm is accurately oriented with respect to a known azimuth heading (typically True North) and the sensor is correctly calibrated internally.

In order to obtain correct wind direction readings, the F460 wind direction transmitter must be checked for proper internal azimuth alignment using the Climatronics azimuth linearity test fixture (P.N. #101754), which ensures a precise and correct physical alignment is maintained between the keyed hub for vane attachment, the sensor's internal signal transducer (potentiometer) and the sensor's keyed crossarm mounting socket. Subsection 10.2.2.5 provides a detailed procedure for this check (under "System Performance Test"). If adjustment is required, the manufacturer's System Engineering Manual should be consulted.

2.3.2.1 Aligning the Climatronics F-460 Crossarm to True North

It is also necessary to accurately orient the F460 crossarm assembly to a known azimuth heading (typically, the heading used is true north). For true north orientation, it is necessary for the scribe mark on the crossarm mounting socket for the wind direction sensor to be facing due south. A compass, surveyor’s transit or Global Positioning System (GPS) device can be used to determine true north by applying appropriate corrections for magnetic declination. Alternatively, true north can be determined for aligning the crossarm using the procedure described in the following subsections.

2.3.2.1.1 Using the True Soar Noon (TSN) Method to Determine True North

An accurate method utilized for accurately orienting the crossarm to true north is to utilize the True Solar Noon (TSN) method for determining true north relative to the tower on which the crosssarm will be mounted. In order to utilize the TSN method, True Solar Noon (TSN) for the site longitude on the day of crossarm orientation must first be calculated. Following is a brief explanation of how true north or true south is determined, followed by a discussion of the actual crossarm orientation procedure.

The sun travels at the rate of 15^{o} of longitude per 60 minutes. This rate subsequently reduces to $1/4^{o}$ per minute or 15' of longitude per minute of time. This rate is based upon the mean sun travel rate over the whole year at any longitude. Due to the earth's path of revolution about the sun, its axis angle perturbations and other factors, the sun actually travels at different rates across the sky during the year. When the sun is at the zenith of its path, a shadow produced by an object points to true north in the Northern Hemisphere or true south in the Southern Hemisphere. All of these factors interact in determining true north or true south.

The earth is divided into a series of time zones. Each time zone has a Main Meridian (longitudinal center of the zone). As the sun travels across the zone, it reaches its zenith at different times for different longitudes within the time zone.

For points east of the Main Meridian, the zenith is reached earlier than 12:00 noon while, for points west, it is reached later. The sun reaches its zenith over the Main Meridian of a given time zone at 12:00 noon, Local Standard Time, or "LST". Table 2-1 lists time zones with Main Meridians. Table 2-2 lists the time correction necessary due to a site's longitude difference from the Main Meridian. ALWAYS USE LOCAL STANDARD TIME.

The previous calculations are based on the mean path of the sun across the sky for the entire year at any given longitudinal point. The sun actually varies its track during the year. Table 2-3 lists the additional compensation needed for any day of the year. Adding time means the sun would appear in the sky to the east of its mean path, subtracting means it appears to the west.

The following procedure can be used for determining true north or south.

2.3.2.1.2 Equipment

1) Two stakes (3-4 feet tall), one with a colored tip. The tower may substitute for one stake.
2) A level.
3) Unobstructed sun at the site location at the time of True Solar Noon.
4) Accurate clock (to within 1 minute).
5) Rubber mallet.
6) Climatronics crossarm sighting scope (P.N. 101126) or surveyor's transit.

2.3.2.1.3 Procedure

Part 1: Calculate True Solar Noon for the Tower Site Location

1) Use Table 2-1 to determine the Main Meridian for your time zone.
2) Use a local map or U.S. Geological Survey map to determine your site's longitude to the nearest 15 minutes.
3) Calculate the difference between the site's longitude and the Main Meridian longitude using Equation 1:

Site Longitude - Main Meridian = Longitude difference ***Equation 1***

4) Use Table 2-2 to convert the Longitude difference to a time difference and add or subtract that time from 12:00 noon (standard time).

5) The time calculated in Step 4) is the Base Solar Noon for the site and is the same throughout the entire year. Use Table 2-3 to adjust your Base Solar Noon to True Solar Noon for the particular day of the year.

   NOTE: Always use Local Standard Time (1 p.m. Daylight Savings Time is actually 12 noon Standard Time).

<u>Part 2: Establish True North at the Site Location and Align Crossarm</u>

1) As True Solar Noon time approaches, reference the shadow which is cast from the top mast (uppermost central point) of the tower onto the ground.

2) Drive a stake into the ground at the center of the shadow cast at True Solar Noon.

3) The line defined by the stake and the center of the tower points out true north. Use a surveyor's transit or other accurate straight-line technique to extend this line out from the tower at least 100 feet. Drive a stake or other visible benchmark into the ground exactly centered on this line 100 feet (or more) distant from the tower.

4) Using OSHA-approved climb safety harness and suspension apparatus, climb the tower to access the crossarm. Use lanyard(s) with safety clips to provide a secure, hands-free working position. Install the Climatronics Crossarm Sighting Scope (P.N. 101126) on the north end of crossarm over the mounting socket normally occupied by the F-460 wind speed sensor. Look through the crossarm sighting scope to determine if the true north benchmark established in Step 3 above is centered in the vertical reticule of the sighting scope (adjust the vertical angle of the sighting scope as-needed to view the benchmark). If the true north benchmark is not exactly centered, slightly loosen the two large setscrews located on the center (vertical) pipe rail fitting that secure the crossarm to the tower topmast. Adjust the horizontal azimuth orientation of the crossarm until the true north benchmark is centered on the vertical reticule as viewed through the sighting scope. (Note: the body mass of the climber should be kept centered on the tower when making this adjustment; this will minimize the possibility of the tower "leaning" away from the vertical). When the crossarm is aligned such that the true north benchmark is exactly centered on the vertical reticule in the sighting scope, carefully tighten the crossarm mounting set screws to secure the crossarm in this position. Re-check the crossarm orientation after the set screws are tight.

TABLE 2-1: TIME ZONES VS. MAIN MERIDIAN

Time Zone	Main Meridian
Greenland	45th
Atlantic	60th
Eastern	75th
Central	90th
Mountain	105th
Pacific	120th
Yukon	150th
Bering	165th

TABLE 2-2: LONGITUDE DIFFERENCE VS. TIME ADJUSTMENT					
Longitude Difference From Main Meridian		Time Adjustment (minutes)	Longitude Difference From Main Meridian		Time Adjustment (minutes)
-0^{o}	00' 15' 30' 45'	0 - 1 - 2 - 3	$+0^{o}$	00' 15' 30' 45'	0 + 1 + 2 + 3
-1^{o}	00' 15' 30' 45'	- 4 - 5 - 6 - 7	$+1^{o}$	00' 15' 30' 45'	+ 4 + 5 + 6 + 7
-2^{o}	00' 15' 30' 45'	- 8 - 9 -10 -11	$+2^{o}$	00' 15' 30' 45'	+ 8 + 9 +10 +11
-3^{o}	00' 15' 30' 45'	-12 -13 -14 -15	$+3^{o}$	00' 15' 30' 45'	+12 +13 +14 +15
-4^{o}	00' 15' 30' 45'	-16 -17 -18 -19	$+4^{o}$	00' 15' 30' 45'	+16 +17 +18 +19
-5^{o}	00' 15' 30' 45'	-20 -21 -22 -23	$+5^{o}$	00' 15' 30' 45'	+20 +21 +22 +23
-6^{o}	00' 15' 30' 45'	-24 -25 -26 -27	$+6^{o}$	00' 15' 30' 45'	+24 +25 +26 +27
-7^{o}	00' 15' 30' 45'	-28 -29 -30 -31	$+7^{o}$	00' 15' 30' 45'	+28 +29 +30 +31

TABLE 2-3: DAY OF YEAR ADJUSTMENT

Month	Day	Time Adjustment (Minutes)
January	10 20 30	+ 8 +11 +13
February	10 20 30	+14 +14 +13
March	10 20 30	+10 + 8 + 4
April	10 20 30	+ 1 - 1 - 3
May	10 20 30	- 4 - 4 - 3
June	10 20 30	- 1 + 1 + 4
July	10 20 30	+ 5 + 6 + 6
August	10 20 30	+ 5 + 3 + 1
September	10 20 30	- 3 - 7 -10
October	10 20 30	-13 -15 -16
November	10 20 30	-16 -14 -11
December	10 20 30	- 7 - 2 + 3

Use linear interpolation to determine the time adjustments required for days not listed in the table.

2.3.3 Temperature and Temperature Difference (Δ-T) Installation

2.3.3.1 Motor-Aspirated Radiation Shield Installation

1) Two Climatronics TS-10 series shields are mounted horizontally on the meteorological tower. One shield is mounted at a height of 2 meters (m) above ground level (AGL) and houses the ambient air temperature probe and a relative humidity probe. The second TS-10 shield is mounted at a height of 10m AGL and houses the temperature difference (Δ-T) probe. Each TS-10 shield is mounted with the exhaust vent of the motor housing facing downward so water does not enter the motor blower unit. The open end of the radiation shield should face northward to reduce radiation errors caused by the sun shining into the end of the shield. TS-10 shield assemblies are mounted on the tower by means of a pipe rail fitting or u-bolts attached to a short, vertical, 1-1/4 inch diameter pipe (typically mounted either on the top mast of the tower or on an offset bracket).

2) Access to the blower motor is gained by simply unlatching the two latches of the motor housing cover. A safety cable keeps the motor housing cover connected to the main shield body and eliminates the risk of dropping the cover.

2.3.3.2 Temperature and Δ-T Sensor Probe Installation (or Removal)

Installation or removal of either the air temperature or Δ-T probe is made with the 115V AC power for the blower motor disconnected and the corresponding Amphenol connector for AC power delivery to the aspirator DETACHED. The procedure is written in the sequence that would be used for sensor removal, since the radiation shield is typically shipped with the probe already installed. The probe is installed by simply reversing the following steps.

Temperature/Δ-T Probe (P/N 100093) Removal:

1) Looking into the open end of the radiation shield cylinder, you will notice an inner shield assembly with a pull ring.

2) Gently pull on the ring and slide out the inner shield assembly about 2-3 inches.

3) Un-loop the probe’s signal cable from the inner shield slides. The probe’s cable is looped around one of the shield guides that space the inner shield from the outer shield. Remove the entire inner shield.

4) You will notice a thumbscrew at the rear of the inner shield network. Loosen the thumbscrew and remove the probe from the inner shield.

5) To totally remove the temperature or Δ-T probe and cable, you must unlatch and remove the blower motor housing cover and disconnect the probe’s signal cable leads from the terminal strip.

Temperature/Δ-T Probe Installation:

1) To install the temperature or Δ-T probe, reverse the above steps (1 - 5). NOTE: The inner shield assembly must be properly oriented for installation into the radiation shield. Consult the manufacturer's system manual for proper orientation. Be sure to loop the excess length of sensor signal cable over one of the inner shield guides. This will prevent the probe's signal cable from possibly getting caught in the aspirator fan located at the rear of the shield.

2.3.4 Relative Humidity Sensor Installation

Sensor Removal and Installation (P/N 102798)

1) The sensor is easily accessible by unclasping the two latches of the radiation shield aspirator motor housing cover. (Note: *Ensure power to the aspirator motor is disconnected first*!).

2) Remove the motor housing cover to expose the sensor mounted at the base of the shield inlet cylinder in front of the fan.

3) Release the sensor by removing it from the clip that secures it to the base of the shield.

4) Disconnect the sensor signal wire leads from the terminal strip.

5) Perform Steps (1) through (4) above in reverse order to install the sensor into the radiation shield.

2.3.5 Barometric Pressure Sensor Installation

The barometric pressure sensor is pre-mounted in the NEMA 4X enclosure or in the shelter approximately 1.5m above ground level. The NEMA enclosure provides a solid, vertical mounting surface that shields the sensor from direct sunshine and any rough handling and is away from drafts and heaters.

2.3.6 Solar Radiation Sensor Installation

The solar radiation sensor may be mounted on a horizontal boom projecting from the face of the tower or on a rigid platform or pedestal (typically embedded in the ground).

Option 1: Boom-Mounted Solar Radiation Sensor:

1) The radiation sensor is mounted on a 5-foot long, 1-inch diameter aluminum pipe rail that serves as a fixed-position horizontal boom. The boom is secured to a meteorological tower (or other suitable structure) by means of a U-channel with spring nuts, bolts and adjustable brackets. The boom should be installed so that it is level and rigidly secured to the supporting structure.

2) Rail Fitting Assembly: A right-angle pipe rail fitting is bolted to the underside of the cast aluminum sensor mounting plate. The rail fitting (with the sensor and mounting plate attached) is slipped onto the aluminum pipe rail boom, allowing the sensor to be secured in an upwards-facing position at any point along the length of the boom by means of integral set screws.

3) The shielded signal cable that transmits the sensor's electrical output (measurement) signal to the digital data acquisition system, attaches to the sensor via a keyed, weatherproof, bayonet-type connector. Align the keyed surfaces in the cable connector with the matching surfaces on the sensor output connector, insert, and rotate the knurled outer locking ring ~1/2 turn clockwise to secure the connection.

4) Re-check the sensor's integral spirit level indication and re-level the sensor as-needed using the three knurled thumbscrews located around the perimeter of the sensor base.

5) Reverse Steps 1-4 above to remove the sensor.

Option 2: Pedestal-Mounted Solar Radiation Sensor:

1) A pedestal mount may be fashioned from a square plate (8" x 8" and $^{3}/_{16}$" thick) of galvanized steel or aluminum welded to the top of a 2" to 3" diameter galvanized steel pipe. The other end of the pipe is embedded below grade in a concrete footer block (approximately 1' x 1' x 2'D), ensuring the pipe is vertically plumb and the surmounting plate level. The overall height of the pedestal above grade is typically 1~1.5m.

2) The solar radiation sensor is mounted on the top side of the plate by means of three bolts evenly spaced around the perimeter of the sensor base. Align the holes located on the perimeters of the sensor and cast aluminum mounting plate and pass the bolts through; lightly fasten the bolts with the supplied nuts.

3) Three additional knurled "thumb screws" located on the perimeter of the sensor base allow the sensor to be leveled. An integral spirit level on the base provides a visual indication for leveling.

2.3.7 Precipitation Gauge Installation

The rain gauge will be mounted on a rigid platform 0.5m (in locales free of snow and debris) to 2 m above ground level. The ground surrounding the gauge will be natural vegetation, and should be kept to a height of 6 inches or less (well below the sensor inlet height).

Sensor Installation:

1) Mount the gauge to the platform with the three mounting brackets provided on the gauge. The holes in the mounting brackets are sized for 1/4 inch diameter mounting bolts.

2) Remove the outer shield to expose the base plate and tipping bucket mechanism.

3) Level the gauge using the spirit level mounted on the base plate. Washers can be used as leveling shims between the mounting brackets on the gauge and the platform.

4) The tipping bucket assembly has been taped at the factory to maintain calibration during shipment. Gently remove the tape and assure the bucket tips to both sides easily and without friction.

5) Reinstall the outer shield. Ensure that the debris screen is installed in the gauge's collection opening.

3. PARAMETER METHODOLOGIES

This section provides a detailed description of the operation of each sensor from development of the signal at the sensor and continuing to the data logger.

3.1 SENSOR OPERATIONAL DESCRIPTIONS

3.1.1 Wind Speed Transmitter (P/N 100075)

The F460 Wind Speed Transmitter is designed for low threshold (< 0.22 m/s) and fast response, a large dynamic measurement range, and the ability to operate in adverse environments. Wind Speed is sensed by a low-friction, three-cup anemometer, the body of which is made of machined aluminum. The cups assembly is constructed of either aluminum or Lexan. The transfer function is identical for either type of cup material.

A photo chopper, consisting of a lightweight, chemically etched disk divided into 30 sections and located within the sensor body, rotates with the cups assembly. As the disk rotates, the light path between an infrared light emitting diode and a photo transistor is alternately blocked and left clear. In order to minimize power consumption, the power to the light emitting diode is turned on for only 10 microseconds every 0.25 milliseconds. The photo diode, photo transistor and supporting electronic circuitry housed within the sensor detect and convert the light pulses produced by the rotational speed of the photo chopper disk to a square wave electrical output signal whose frequency is proportional to the wind speed. This signal is fed through a signal cable to the input of the data logger.

3.1.2 Vertical Component Anemometer (P/N 102236)

Climatronics' Vertical Component Anemometer (P/N 102236) is the latest generation of vertical wind speed sensors. An exceptionally low threshold (<0.14 m/s) and fast response are achieved through the use of mechanical features found in the proven F460 wind sensors. The anemometer body is slender and aerodynamic to ensure that minimal turbulence is introduced into the measured air stream. The component anemometer is supplied with an expanded polystyrene (EPS) propeller featuring low threshold.

Propeller rotation causes a 3-slot shutter to interrupt a solid-state light source. This pulse signal is processed by an internal signal conditioner which utilizes state-of-the-art surface mount technology. The sensor produces a dual frequency and linear millivolt DC output. Both signal outputs allow for full compatibility with Climatronics' and many other signal conditioning and data acquisition products. The component anemometer mates to its mount (P/N 102234) with a weatherproof connector. The mount features a choice of three standard pipe adapters and includes a shielded signal cable prewired to the mating connector. The cable length may extend upwards of 1,000 ft. with no appreciable loss in signal strength or quality.

3.1.3 Wind Direction Transmitter (P/N 100076)

The Climatronics' F460 Wind Direction Transmitter is designed for low threshold (0.2 m/s), fast response and the ability to operate in adverse environments. Wind direction is sensed by a lightweight, counterbalanced, magnesium vane. Vane position is converted to an electrical signal by a precision low-torque potentiometer and sent to the data logger as two ratiometric DC voltages. A 1/32 amp fuse is connected in series with the potentiometer to prevent damage if excessive current is induced in the system (e.g., electrical surges).

3.1.4 Aspirated Radiation Shields

The air temperature and temperature difference sensors will be housed within a Climatronics Model 100325-2 radiation shield mounted at each measurement level (i.e., 2m and 10m) to minimize bias of the data that can result from solar radiant heating effects and insolation. The Model 100325 radiation shield is motor-aspirated, providing a continuous flow of ambient air past the sensors to yield accurate measurement values, and has superior serviceability features. The quick-release motor cover and convenient access to the probe housed within make it one of the most serviceable tower-mounted aspirators available. The forced aspiration and triple shield design ensure that errors resulting from radiation and insolation effects are minimized to less than 0.2^oC.

3.1.5 Temperature Sensor (P/N 100093)

Ambient air temperature will be measured at a height 2 and 10m using the Climatronics Model 100093 composite (dual-element) thermistor temperature sensor. The Model 100093 accurately measures the air temperature air temperature in still or moving air when used with Model 100325 motor aspirated radiation shield (see 3.1.3 above). The data logger will be programmed to automatically subtract each instantaneous 10m temperature value from the corresponding 2m temperature value, thereby deriving, averaging and reporting the Δ-T ("Δ-T") between the 2m and 10m levels.

The relationship of the dual thermistor's variable resistance characteristic to temperature is very linear. The known error due to nonlinearity reaches a maximum of $\leq 0.16^oC$ at about -10°C and $+40^oC$. Other temperature measurement system errors are due to solar radiation ($\leq 0.1^oC$) and the accuracy of the thermistor itself ($\leq 0.15^oC$). Thermistor non-linearity errors are compensated for by means of an offset programmed into the data logger. As a consequence, air temperature total measurement error is $< \pm 0.5^oC$ across the measurement range. Temperature difference measurements obtained between two Model 100093 probes, each mounted in a Model 100325-2 radiation shield, have a relative accuracy of $\pm 0.1^oC$.

3.1.6 Relative Humidity (RH) Sensors

Relative humidity (RH) will be measured at a height of 2 m AGL using the Climatronics Model 102273 thin-film capacitive sensor, an exceptionally stable sensor with response time of (≤10 seconds without filtering). This sensor requires a minimum of maintenance or calibration and features exceptional resistance to contaminants. Repeatability is excellent, even after complete sensor saturation. The Model 102273 sensor maintains its accuracy over the full range of humidity, even in conditions close to condensation. This is accomplished by electronic temperature compensation.

The sensor’s signal is processed by an internal signal conditioner which utilizes state-of-the-art surface mount technology. The sensor output is a 0-1VDC signal that is directly proportionate to the instantaneous RH condition.

3.1.7 Barometric Pressure (BP) Sensor

Barometric pressure (BP) will be measured by the Climatronics Corp. Model 102270-G3 BP sensor. The 102273-G3 features a built-in application-specific integrated circuit (ASIC) which works hand-in-hand with a capacitive transducer to achieve long-term stability (sensor calibration drift is < ±0.25% of full scale over 6 months at 70°F) and high accuracy. The sensor provides calibrated pressure readings over the range of 800 to 1,100 millibars (mb) or 23.62 to 32.48 inches of mercury (inHg) with an accuracy of ±0.1% of full scale (< ±0.3 mb or < ±0.01 inHg) over an operating temperature range of -20° to 80°C.

3.1.8 Solar Radiation Sensor (Eppley Model 8-48)

The Eppley Model 8-48, or “Black & White” pyranometer is a wirewound plated thermopile arranged in alternating black and white elements (“star” pattern) surmounted by a ground and polished “Schottky” hemispheric glass dome. It converts radiant solar energy to a linearly proportionate electrical current signal in accordance with the Lambert cosine response law. Built-in temperature (thermistor) compensation provides a response independent of normal ambient temperature effects. The thermopile and dome assembly are sealed against weather and air exchange. The sensor has an integral, user-serviceable desiccant chamber to minimize condensation inside the glass dome. For each sensor, the manufacturer provides a unique temperature-dependence calibration curve (from -20 to +40^{o}C) traceable to standard self-calibrating cavity pyrheliometers which participate in the International Pyrheliometric Comparisons (IPC) every five years. Cosine response accuracy is ±≤2% from normalization (0^{o}) to 70^{o} zenith angle and ±≤5% from 70^{o} to 80^{o} zenith angle. Temperature dependence is ≤±1.5% constancy from -20 to +40^{o}C and linearity is ≤±1% from 0 to 1,400 watts per square meter (W/m^2). Response time is 5 seconds (^{1}/e signal).

3.1.9 Precipitation

Precipitation will be measured with the Climatronics Corp. Model 100097 precipitation gauge. The Model 100097 is a tipping bucket-type gauge that has a screened, 8-inch diameter collection funnel opening. Precipitation is channeled to one of two triangular buckets, which are balanced on a pivoting arm and alternate in the sample collection position under the funnel. When a pre-determined volume of water accumulates in a bucket, the weight will cause the bucket to tip the balanced arm, thereby raising the other bucket into the collection position under the funnel. Each bucket tip represents 0.01 inches of precipitation as liquid-phase water. When a bucket tips, it momentarily activates a sealed reed switch, which sends an event message to the signal conditioner or data acquisition system. Upon tipping, the accumulated water within the bucket is drained. The Model 100097 precipitation gauge has a measurement accuracy of ≤ ±1% for rainfall rates of up to three inches per hour and ≤ ±3% for rainfall rates of up to six inches per hour.

4. CALIBRATION CONTROL STRATEGY

This section discusses field calibration of the meteorological measurement systems.

4.1 DATA LOGGER CALIBRATION CONTROL

Meteorological measurement output voltages are sampled, averaged and stored for retrieval in the digital data acquisition system. For the monitoring program, this instrument is the Campbell Scientific CR1000 data logger. The data logger output is included in all calibration checks performed on the monitors, including initial installation startup calibrations and all subsequent performance audit and other system performance checks. The CR1000 self-calibrates to compensate for changes induced by fluctuating operating temperatures and long-term aging effects on electronic components.

The CR 1000 has an accuracy specification of ±0.12% of reading. The CR 1000 automatically performs self-calibration during spare time in a slow sequence (background), with a segment of the calibration occurring every 4 seconds. Re-calibration of the data logger is performed whenever the data logger response to a defined, NIST-traceable input voltage exceeds established control limits. If, during any calibration check of the meteorological measurement system, it becomes evident that any of the data logger responses exceed the acceptability limit for accuracy, and the fault is not attributable to an error in the specified input voltage, the data logger will be checked for correct operation and re-calibrated as necessary.

4.2 SENSOR CALIBRATION CONTROL

Complete meteorological system performance checks include authoritative assessment of sensor accuracy and performance parameters. These tests are performed at minimum semi-annual intervals both prior to and immediately following any maintenance on the sensors which could affect their performance characteristics (assuming the sensors are operational prior to performing the maintenance).

The system performance checks conducted *prior* to any scheduled preventive maintenance on the sensors serve to assess and document the "As Found", or unadjusted, performance and accuracy of the entire meteorological measurement system. Following completion of any maintenance or adjustment to the instruments, the measurement system is again performance-tested and the results documented to ensure the system's "As Left" performance meets the acceptability criteria established in support of data quality objectives for the meteorological monitoring program.

Scheduled system performance checks are conducted on-site at minimum semi-annual intervals under the auspices of a technically qualified, experienced auditor. The test data and results of the scheduled system performance checks described above are collectively referred to as an independent meteorological audit. Unscheduled system performance checks are also performed on an as-needed basis by the network operator if the proper operation of the meteorological measurement system is suspect.

Procedures for conducting complete system performance checks are described in Section 10. The procedures described in Section 10 are performed within 30 days of startup, and at minimum subsequent semi-annual intervals.

Spare sensors, whether maintained at the monitoring site location or at Enviroplan Consulting's service facilities, are performance-tested using the same methods and acceptability criteria described in Section 10. These sensors are maintained as calibrated spares in case of malfunction or failure of the currently operating sensors. Section 7 in this document provides procedures for performing both preventative and corrective maintenance on the system, including associated performance tests and documentation of maintenance activities and performance test data obtained in conjunction with maintenance activities.

5. ROUTINE CHECKS OF DIGITAL DATA ACQUISITION SYSTEM

This section provides a detailed description of routine checks of the digital data acquisitions system (DAS).

5.1 OVERVIEW

The digital data acquisition system used in this monitoring program is a Campbell Scientific CR1000 data logger. The CR1000 is a precision instrument designed for demanding, low-power measurement applications. The central processing unit (CPU), analog and digital inputs, analog and digital outputs, and memory are controlled by the operating system in conjunction with the user program. The user program is written in CRBASIC, a programming language that includes data processing and analysis routines and a standard BASIC instruction set. The CR1000 support software facilitates program generation, editing, data retrieval, and real-time data monitoring.

For a more detailed overview of the CR1000 data logger and its programming and support software, please refer to Campbell Scientific's CR1000 User Manual, Campbell Scientific's LoggerNet User Manual, and Climatronics' Engineering Manual for this project.

5.2 CARE AND MAINTENANCE

The CR1000 is a 100% solid state device designed to function in all ranges of temperate climates and from 0-95% (non-condensing) relative humidity. The instrument does not require any scheduled preventive maintenance except possible replacement of the internal lithium battery once per decade (or less frequently; see Section 4.2.4 below), and should give many years of reliable service.

5.2.1 Protection from Water

The CR1000 must be protected from liquid moisture. Contact of the instrument electronics with liquid moisture will likely cause serious and unrepairable damage to the CR1000. Water can come from flooding or sprinkler irrigation, but most often comes as condensation. Protecting from water is as easy as placing the CR1000 in a weather tight enclosure with desiccant. The CR1000 is shipped with desiccant to reduce humidity. Desiccant should be changed periodically. The CR1000 is housed in a NEMA 4X (watertight, dust-tight, corrosion-resistant, indoor and outdoor use) enclosure or within the climate-controlled monitoring shelter. Do not completely seal the enclosure if lead acid batteries are present.

If internal moisture is present in the enclosure or on the surface of any electrical connection, the field operator should immediately contact Enviroplan Consulting's technical staff for support and recommended solutions.

5.2.2 Protection from Voltage Transients

The CR1000 must be grounded to minimize risk of damage by voltage transients associated with power surges and lightning induced transients. Earth grounding is required to form a complete circuit for voltage clamping devices both internal and external to the CR1000. Surge protection devices are an integral part of the system and are housed inside of the NEMA enclosure. Heavy-gauge (e.g., ≥AWG 6) stranded copper cable should be used to connect the earth ground lug inside the NEMA 4X enclosure that houses the data logger directly to the ground rod installed at the base of the meteorological tower.

5.2.3 Calibration

The CR1000 uses an internal voltage reference to routinely calibrate itself. The CR1000 self-calibrates to compensate for changes induced by fluctuating operating temperatures and aging effects on internal electrical components. Self-calibration is automatically performed during spare time in a slow sequence (background), with a segment of the calibration occurring every 4 seconds.

5.2.4 Internal Battery

The CR1000 contains a 3VDC lithium battery that operates the clock and SRAM when the CR1000 is not powered. The CR1000 does not draw power from the lithium battery while it is powered by a 12VDC supply. In a CR1000 stored at room temperature, the lithium battery should last approximately 10 years (less at temperature extremes). Where the CR 1000 is powered most or all of the time, the lithium cell should last much longer.

The meteorological system utilized in this monitoring project also uses a back-up 12VDC lead-acid battery or universal power supply in the event of power outages. The back-up battery will provide power for the data logger and the sensors ensuring continuous data collection in the event of a power outage.

5.3 LOCAL COMMUNICATION USING CR1000KD KEYBOARD DISPLAY

Local communications with the data logger can take place using the RS-232 and CS I/O ports integrated with the CR1000 wiring panel. Instantaneous and historical data values from the data logger can be obtained. On-site serial communications are available using the CR1000KD keyboard display or by connecting a laptop computer to the CR1000. This Section will cover local communications using the keyboard display and Section 5.4 will cover local communications using a laptop computer. Section 5.5 covers TCP/IP communications with the data logger using a cellular modem device.

5.3.1 Equipment Required

- CR1000KD Keyboard Display.
- SC12 Two-Peripheral Connector Cable (2’ long).

5.3.2 Procedure to Establish Local Communications With CR1000 Data Logger

The CR1000KD keyboard display can communicate and retrieve data using its default menus. Connecting and using the default menus to retrieve real-time and historical data is described below. Other functions may be accomplished using the keyboard display, but care must be exercised to not alter any data logger settings. The Operations Manual for the CR1000 Data Logger should be referred to for functions other than viewing instantaneous and historical data.

1. Connect the CR1000KD to the data logger's CS I/O port using the SC12 peripheral cable.

2. The CR1000KD should power up. If the keyboard display does not power up, press any key to turn on the display.

3. The **Up** and **Down** arrow keys can be used to move the cursor. Move the cursor so that ***Data*** is highlighted. Press the ***Enter*** key to display a list of options available for viewing data.

4. To view real-time data, move the cursor so that ***Real Time Tables*** is highlighted. Press the ***Enter*** key. A list of data tables created by the data logger's program will be displayed. The following list of data tables should be displayed:

   a. Public – displays instantaneous data;
   b. Table1 – displays one-minute averaged data;
   c. Table 5 – displays five-minute averaged data; and
   d. Table60 – displays hourly-averaged data.

5. Move the cursor to the field in which the data that is desired to be displayed is highlighted. Press the ***Enter*** key to display the data.

6. The keyboard display can be left connected to the data logger when not in use. It will automatically turn its display off after one minute or the display can be manually turned off by pressing ***End***.

5.4 LOCAL COMMUNICATION USING A LAPTOP COMPUTER

Serial communications to the data logger can be accomplished using a laptop with a DB-9 serial cable connected to the RS-232 port on the CR1000. If the laptop is not equipped with a serial port, a USB-to-Serial Port adapter can be utilized. While communicating with the data logger, the operator should exercise care not to select any software functions that could alter any of the data logger configuration parameters.

5.4.1 Equipment Required

- PC-type laptop computer equipped with a serial port or Ethernet port and Microsoft Windows [tm] 7 or Windows XP operating system.

- DB-9 serial communications cable (6' to 10' long) or Cat 5-e Ethernet cable.

- Optional: If the laptop computer lacks a serial port, you will need a USB to Serial Port communications adaptor and driver software.

- Campbell Scientific LoggerNet software

5.4.2 Procedure to Establish Local Communications With CR1000 Data Logger

If the laptop computer lacks a serial port, install a USB to Serial Port communications driver onto the PC. Follow the prompts on the installation software. Using Device Manager, which is found on the Hardware tab in the System folder in Control Panel, confirm which ComPort the USB to Serial Driver was assigned to.

1. Install the LoggerNet software from the diskette.

    a. Insert the diskette into the disk drive and close. The installation software should start automatically. NOTE: If the installation software does not start automatically, go to ***Start*** menu from the Desktop, go to ***Run***, select ***Browse***, find the drive path for your disk drive, select ***AutoRun***, and click ***Open***. The installation software should start.

    b. Follow the prompts to install the LoggerNet software.

2. Connect one end of the serial communications cable to the CR1000 serial port labeled "RS-232". Connect the other end of the serial cable to the serial port on the PC or, (if the PC lacks a serial port), to the DB-9 cable port on a USB serial port adaptor and plug the USB connector on this adaptor into the USB port on the laptop PC.

3. Install the pre-configured CR1000 data logger onto the LoggerNet software.

    a. Open the LoggerNet Toolbar by double-clicking on the LoggerNet icon on the desktop.

    b. Configure LoggerNet to communicate with the CR1000 data logger.

        - Click on the ***Setup*** button on the LoggerNet Toolbar to open the Setup screen.
        - Click on the ***Add Root*** button
        - Select ***ComPort***
        - Select P***akBusPort*** (Other Loggers)
        - Select ***CR1000***
        - Click the ***Close*** button. You will still be in the Setup screen.

4. Set up the CR1000 installation for access to the data logger via a ComPort.

a. Click on the ***ComPort*** Node.

- The ***Communication Enabled*** button should be checked.
- In the ***ComPort Connection*** window, if the laptop has a serial port, select the ComPort number the serial port is assigned to (usually Com 1). If the laptop has no serial port, select the ComPort number that was assigned to the USB Serial Driver during installation of that driver software.

b. Click on the ***PakBusPort*** node.

- The ***Communications Enabled*** button should be checked.
- Set the ***Maximum Baud Rate*** window to 115200.
- The ***PakBus Address*** should be 4094.

c. Click on the ***CR1000*** node.

- The ***Communications Enabled*** button should be checked.
- The ***Call Back*** button should be unchecked.
- The ***Automatic Hole Collection*** should be *unchecked* (Disabled).

d. Click on ***Apply***. Close the LoggerNet Setup screen.

The installed LoggerNet is now configured to allow local communication with the CR1000 data logger. Refer to the LoggerNet User's Manual for additional information on how to use this menu-driven software to obtain the desired information from the installed CR1000 data logger. While communicating with the data logger, the operator should exercise care not to select any software functions that could alter any of the data logger configuration parameters.

5.5 INTERNET COMMUNICATION WITH DATA LOGGER

This section provides instructions on how to establish communications with the CR1000 data logger using a PC and an internet service provider (ISP) connection from a remote location. This type of connection can be used to obtain instantaneous and historical data values from the data logger. While communicating with the data logger, the operator should exercise care not to select any software functions that could alter any of the data logger configuration parameters.

5.5.1 Equipment Required

- PC-type computer with an active internet service connection and running Microsoft Windows tm 7 or Windows XP operating system.

- Campbell Scientific LoggerNet software

5.5.2 Procedure to Establish Internet Communications With CR1000 Data Logger

1. Install the LoggerNet software from the diskette onto the remote PC.

    a. Insert the diskette into the disk drive and close. The installation software should start automatically. NOTE: If the installation software does not start automatically, go to ***Start*** menu from the Desktop, go to ***Run***, select ***Browse***, find the drive path for your disk drive, select ***AutoRun***, and click ***Open***. The installation software should start.

    b. Follow the prompts to install the LoggerNet software.

2. Set-up LoggerNet for an internet connection from the PC to the CR1000 data logger.

    a. Open the LoggerNet Toolbar by double-clicking on the LoggerNet icon on the desktop.

    b. Install the CR1000 data logger into LoggerNet.

        - Click on the ***Setup*** button on the LoggerNet Toolbar to open the Setup screen.
        - Click on the ***Add Root*** button
        - Select ***IPP Port***
        - Select ***PakBusPort*** (Other Loggers)
        - Select ***CR1000***
        - Click the ***Close*** button. You will still be in the Setup screen. You will need this for the next step.

3. Set up the CR1000 installation for access to the data logger over the Internet.

    a. Click on the ***IPPort*** Node.
        - The ***Communication Enabled*** button should be checked.
        - In the Internet IP Address window, type in the following IP Address of the CR1000 data logger used in OGR: **9735130080.eairlink.com:3001**
        - Increase the Extra Response Time to ***04s***.

    b. Click on the ***PakBusPort*** node.
        - The ***Communications Enabled*** button should be checked.
        - The ***Extra Response Time*** window should be set to ***04s***.
        - The ***PakBusAddress*** should be ***4094***.

    c. Click on the ***CR1000*** node.
        - The ***Communications Enabled*** button should be checked.
        - The ***Call Back button*** should be checked.
        - The ***Automatic Hole Collection*** should be *unchecked* (Disabled).

    d. Click on ***Apply***. Close the Setup screen.

The installed LoggerNet is now configured to allow communication with the CR1000 data logger via the internet. Refer to the LoggerNet User's Manual for additional information on how to use this menu-driven software to obtain the desired information from the installed CR1000 data logger.

6. ROUTINE CHECKS OF METEOROLOGICAL MONITORS

This section discusses procedures for conducting routine checks on the meteorological monitors. These checks provide a documented, qualitative check of the operational integrity of the instrumentation operated at the meteorological station. A checklist (Form 6-1) is used to document the results of these checks. An example of this checklist appears at the end of this section.

6.1 PURPOSE AND SCOPE

The purpose of this procedure is to provide documentation and instruction for conducting qualitative operational checks and routine field data review of the meteorological monitoring system, which includes:

- Horizontal Wind Speed
- Wind Direction
- Vertical Wind Speed
- Temperature and Temperature Difference
- Relative Humidity
- Barometric Pressure
- Solar Radiation
- Precipitation
- Data Acquisition System
- Meteorological Tower

6.2 FREQUENCY

Checks should be conducted at a minimum frequency of once every two weeks. In the event that communications are not available with the on-site DAS (preventing remote daily data polling and review) a minimum of two site checks per week should be conducted.

6.3 REFERENCES

- Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurement Systems, EPA-454/B-08-002, March 2008;

6.4 EQUIPMENT AND MATERIALS

- Form 6-1: Meteorological System Checklist
- Hand-held calculator
- Soft, lint-free cloth
- Binoculars (optional)

6.5 PROCEDURE

6.5.1 Meteorological Sensor Checks

Visually inspect the tower-mounted instruments, barometric pressure sensor, precipitation gauge and solar radiation sensor for any signs of damage or malfunction. Use binoculars to inspect the tower-mounted instruments if necessary.

If evidence of damage or malfunction is detected, see "Preventive and Corrective Maintenance" (Section 7) for corrective action procedures. Complete a Non-Conformance/Corrective Action (NC/CA) report describing the problem, investigative and corrective actions taken (refer to Section 9.3 in this document for a discussion of NC/CA reports). Record a *clear, concise, chronological summary of all investigative and corrective actions taken* in the on-site logbook as well. Note any problems and status of resolution in the “Comments” section of Form 6-1 (Meteorological System Checklist).

6.5.1.1 Wind Speed Sensor Checks

- Anemometer cups or propeller should be spinning at rate consistent with prevailing wind speed conditions (the capability to make this qualitative assessment increases with operational experience).

- Check that the sensor body is plumb, rigidly mounted and that there are no holes, cracks, dents or improper alignment (tilting) in cups.

6.5.1.2 Wind Direction Sensor Checks

- The wind vane should be moving and aligned with the direction from which the wind is blowing.

- Check the vane for holes, cracks, bends or deviations (tilting) from the horizontal plane.

- Check that the sensor body is plumb and rigidly mounted.

- Check the crossarm position for any visible evidence of change from its normal orientation to true north. (Note: the wind speed sensor is normally mounted on the end of the crossarm that points to the north).

6.5.1.3 Temperature and Relative Humidity Sensor Checks

- Verify that the radiation shields are properly orientated and rigidly mounted.

- Listen to confirm aspirator fans are running at both levels on the tower.

- Verify that the radiation shield housings are clean.

6.5.1.4 Solar Radiation Sensor Checks

- Check the sensor and mounting hardware for any signs of physical damage. Ensure the sensor is rigidly mounted and correctly oriented (facing upward).

- Check the sensor's glass dome for clarity. Use a soft, lint-free cloth to clean away any dust or foreign material. Check for any evidence of liquid moisture (condensation) within the glass dome and on the thermopile. If liquid moisture is present, corrective actions must be taken.

- Check the desiccant color (viewable through the clear glass window on the side of the sensor body). If the color is blue, the desiccant condition is acceptable. If the color is white or pink, the desiccant is spent and must be replaced.

- Check the sensor's integral spirit level. If the bubble is centered, the sensor is acceptably level. If the bubble is substantially outside the center ring, the sensor's mounting will require adjustment for proper leveling.

6.5.1.6 Precipitation Sensor Checks

- Check the funnel screen and tipping buckets and carefully remove any dust or debris that may have collected. If the buckets need cleaning, avoid tipping the buckets or putting excessive pressure on the bucket pivot bearings. Indicate in the site logbook and on Form 6-1, Routine Site Check Form the date and time of tipping bucket cleaning so that no erroneous data due to inadvertent tipping of the bucketsis incorporate into the database.

- Trim any vegetation around the base of the rain gauge.

6.5.1.7 Barometric Pressure Sensor Checks

- Verify the sensor is securely mounted within the NEMA 4X enclosure that houses the data logger and surge protection modules and that there is no liquid moisture on or around the sensor.

6.5.2 Review of On-Site Logbook Documentation

Review the last few entries in the chronological site logbook and update this record:

- Entries should be complete, concise, and legible.

- Each entry should be signed by the operator with the date, time of arrival and time of departure.

- A concise summary of all activities and QC check results should be entered.

- See that problems entered have been closed. If not, follow up on the plan of action that is required for each problem, and record progress and status changes as they occur.

- Begin entry for this visit in chronological site logbook. Enter date, time of arrival on-site, and reason for visit (e.g., "conduct routine system checks").

6.5.3 <u>Compare Current DAS Data to Ambient Conditions (All Parameters)</u>

The operator should compare the current data values indicated by the DAS for internal consistency as well as agreement with corresponding current ambient conditions. A laptop PC or the CR1000KD keyboard display are needed to interface with the data logger's RS-232 port to obtain the current data values (refer to Section 5.3 for the procedure for establishing local communications with the CR1000 data logger). The instantaneous data available are already scaled in engineering measurement units.

For each parameter, compare the instantaneous measurement value obtained from the DAS with corresponding current ambient conditions. A reasonable level of agreement should result from this qualitative assessment.

(a) **<u>Wind Speed</u>:** Estimate the current ambient wind speed by visually observing the rotational rate of the sensor's cups assembly or propeller (the operator will become proficient at this with practice). Verify the current DAS-indicated wind speed agrees reasonably well with the visually-estimated wind speed indicated by the cups instantaneous rotational rate.

(b) **<u>Wind Direction</u>:** Estimate the current the wind direction value by observing the wind direction sensor's vane angle relative to the north-south axis of the Climatronics crossarm. Verify the current DAS-indicated wind direction agrees reasonably well with the visually-assessed wind direction indicated by the instantaneous vane position.

(c) **<u>Air Temperature</u>:** Evaluate the current DAS-indicated ambient air temperature for:

- Reasonable agreement with current local radio weather report value or a reasonably accurate mercury-in-glass thermometer kept at the site for this purpose (<u>Note</u>: obtain any thermometer readings in a shaded area away from sources of hot or cold air).
- No rapid, large-magnitude changes (very low variability over short-term intervals).

(d) **<u>Temperature Difference</u>:** Evaluate the current DAS-indicated temperature difference ("Δ-T") value for:

- No rapid, large-magnitude changes (very low variability over short-term intervals);
- Reasonable agreement with current air temperature (2m) value; and
- Reasonable agreement with typical Δ-T diurnal cycle values (i.e., slightly negative values during sunny daytime hours transitioning to slightly positive values during nighttime hours).

(e) **<u>Relative Humidity</u>:** Evaluate the current DAS-indicated relative humidity values at the 2m level for:

- Reasonable agreement with current local radio weather report value; and

- No rapid, large-magnitude changes (very low variability over short-term intervals).

(f) **Solar Radiation:** The current DAS-indicated solar radiation data should agree with current, local conditions of the intensity of sunshine as modulated by cloud cover and the solar angle relative to the horizon.

- A bright, sunny, cloudless, summer day at noon in Missouri will typically produce solar radiation values in the range of 900 to 1,100 W/m^2.
- At night, DAS-indicated solar radiation data should be 0 W/m^2 (±2~3 W/m^2).

(g) **Precipitation:** Evaluate the current DAS-indicated value for precipitation for:

- Agreement with current conditions. **NOTE:** DAS precipitation values represent a *totalizing* (counting) function (i.e., *total* inches of precipitation per hour).
- The DAS should never indicate a negative precipitation value.

(h) **Barometric Pressure:** Evaluate the current DAS-indicated barometric pressure value for reasonable agreement with current local radio weather report value.

(i) Record the results of the DAS data comparisons against current ambient conditions in the spaces provided on Form 6-1.

(j) If the operator finds a significant discrepancy exists between current DAS readings and corresponding ambient conditions, he should investigate further. If the discrepancy persists, a full system performance test should be conducted on the suspect measurement system as soon as practicable. Refer to Section 10 in this document for procedures for conducting system performance tests.

6.5.4 Digital Data Acquisition System (DAS) Checks

(a) Check the current data logger (CR1000) time indication. The data logger should indicate current Local Standard Time (LST) (NOT daylight savings time). A reasonably accurate timepiece or broadcast media time announcement may be referenced to make this routine check. If a significant discrepancy exists (more than 5 minutes), then the operator should repeat the check using a NIST-traceable time standard as a reference. If the data logger time clock indication is within ±5 minutes of the NIST-traceable reference standard time indication, no further action is necessary.

(b) Check the status of the voltage of the back-up battery. The charger/regulator connected to the back-up battery maintains a steady charge state of ~13 VDC. If the data logger's back-up battery is less than 13 VDC, it may not be receiving a charge current from the charger or the site may not be operating on mains power. If the back-up battery voltage is less than 13 VDC, investigative actions must be undertaken to determine the time at which the unacceptable condition or event began and the cause of the condition or event. A review of recent monitoring activities recorded in the site logbook and a review of the data record will help to establish this information. Consultations with project management and technical support staff may be helpful as well.

Corrective actions must also be undertaken to resolve the problem and restore the data logger function to normal operation. At the monitoring site, this may involve checking the mains power connection and circuit breaker.

If the results of the investigation determine the assignable cause of the problem is attributable to a malfunction in the data logger, establish a plan of action to effect repairs and implement the plan.

(d) Enter any problems in the appropriate place on Form 6-1 and in the chronological site logbook. Promptly inform project supervisory personnel via telephone or email regarding any problem detected. In consultation with supervisory or technical support personnel, develop an Action Plan to resolve any problems and implement the plan. Enter any changes in the status of the problems as they occur and, if resolved, indicate so in the site logbook. Continue to update supervisory personnel regarding the status of the problem and Action Plan implementation.

(e) Complete a Non-Conformance/Correct Action (NC/CA) Report for each instance of unacceptable data logger check results (refer to Section 9.3 in this document for a discussion of NC/CA reports).

6.5.5 Restoration

Ensure all documentation is complete and all monitoring instruments and systems are either operating normally or, if a problem is extant, that the problem condition has been clearly communicated to supervisory personnel, that an Action Plan has been developed to identify the cause and resolve the problem, and that documentation of the salient aspects of the problem has been properly initiated and/or completed.

6.5.6 Documentation

- Meteorological System Checklist (Form 6-1)
- Site Logbook
- NC/CA Form (if applicable)

FORM 6-1: METEOROLOGICAL SYSTEM CHECKLIST

Network:	Month/Year:
Site:	Operator:

Date and describe any problems and maintenance performed in “Comments” section below

Dates of Checks →					
1. Are horizontal wind speed cups spinning and undamaged? (Y or N)					
2. Is the vertical wind speed propeller spinning and undamaged? (Y or N)					
3. Is wind direction vane moving and undamaged? (Y or N)					
4. Is crossarm positioned correctly? (Y or N)					
5. Are all aspirators clean and blower motors functioning? (Y or N)					
6. Is the precipitation gauge level and all parts clean? (Y or N)					
7. Is vegetation around precipitation gauge 6” or shorter? (Y or N)					
8. Is the solar radiation dome clean and no moisture inside? (Y or N)					
9. Is solar radiation sensor desiccant blue? (Y or N)					
10. Is solar radiation sensor level and undamaged)? (Y or N)					
11. Are all monitoring components secure and free from damage? (Y or N)					
12. Is the data logger indicated time accurate? (= L**S**T ± 5 min.) (Y or N)					
13. Does DAS wind direction value agree with prevailing conditions? (Y or N)					
14. Does DAS hor. wind speed value agree with prevailing conditions? (Y or N)					
15. Does DAS temperature value agree with prevailing conditions? (Y or N)					
16. Does DAS Δ-T value agree with prevailing conditions? (Y or N)					
17. Does DAS solar radiation value agree with prevailing conditions? (Y or N)					
18. Does DAS RH value agree with prevailing condition? (Y or N)					
19. Does DAS vert. wind speed value agree with prevailing condition? (Y or N)					
20. Does DAS BP value agree with prevailing condition? (Y or N)					
21. Are there any unresolved problems with MET system? (Y or N; if “Y”, describe problem in “Comments” section and generate NC/CA report if problem could impact on data validity).					

Comments:

Technician:____

ENVIROPLAN CONSULTING

7. PREVENTIVE AND CORRECTIVE MAINTENANCE

This section provides instruction for the various preventive maintenance activities required to help ensure a high level of valid data capture and instrument up time. It should be noted that the monitoring equipment selected for this project is designed for high reliability and low maintenance requirements. Should a problem develop, guidelines for performing corrective maintenance on an as-needed basis are also provided in this section.

With the use of this document, the Climatronics Engineering Manual, a certified digital multimeter and an inventory of spare parts, network operators will be able to successfully identify and repair a failure. In the event of an equipment failure, the Enviroplan Consulting field supervisor or project manager should be notified promptly via telephone and consulted regarding resolution of the problem. If repairs cannot be made in the field, the field supervisor or Enviroplan Consulting project manager will arrange for expedited delivery of a replacement part. In some cases, expert technical assistance provided over the telephone will expedite resolution of the problem. In all cases, prompt notification and resolution of malfunctions are mandatory to ensure the percentage of valid data required for the project's success. Any equipment returned for servicing to Enviroplan Consulting, NJ, should be securely and protectively packed and shipped to the attention of the project manager.

Instrument problems such as excessive calibration drift, non-representative measurement data or instrument malfunction that are not controlled by preventive maintenance must be dealt with by troubleshooting as soon as practicable by the network operator and supported by contact with Enviroplan Consulting’s technical support personnel or the manufacturer, as required.

The Network Field Operator shall maintain a chronological summary of all problems and results of subsequent investigative and corrective actions in the site logbook and, when required, documented on a Non-Conformance/Corrective Action (NC/CA) form (refer to Section 9.3 for guidance regarding NC/CA reports). A brief summary of any problems and corrective actions should also be provided in the “Comments” section of Form 6-1 (Meteorological System Checklist).

7.1 WIND SPEED TRANSMITTER

The wind speed transmitter (or "sensor") is designed for long periods of trouble-free operation in extreme environments. The sensor's calibration is a function of the manufacturer's design, engineering, associated wind tunnel test data and production quality control. The cups or propeller do not have to be matched to a particular sensor for accurate transmitter operation, and are not typically susceptible to damage in normal use, being ruggedly constructed. If, however, the cups or propeller become damaged, immediately contact the Enviroplan Consulting field operations supervisor or project manager. A spare cups assembly and propeller are typically maintained on-site and are easily replaced.

The weekly routine system checks for the wind speed monitoring system (refer to Section 6 in this document) provide frequent verification that the wind speed signal output and associated DAS reading is representative of prevailing conditions, the sensor’s cups or propeller rotate freely, and the cups assembly or propeller is intact and free of damage. Routine preventive maintenance consists of replacing the sensor bearings after approximately six months of cumulative or continuous use. Preventive maintenance is performed in conjunction with the semi-annual meteorological performance audits following completion of "As Found" system performance tests. Following completion of the maintenance, "As Left" system performance tests are conducted. Refer to Section 10.2.1 in this document for instructions on performing wind speed system performance tests.

Investigative action followed by appropriate corrective maintenance is required if a routine system check or performance test of the system indicates the sensor has excessive internal friction (barring calm conditions). This condition reduces the sensor's ability to accurately respond to low wind speeds.

7.1.1 Wind Speed Bearing Check and Maintenance Procedure

If a routine system check or performance test of the system indicates the sensor has excessive internal friction, or if the sensor bearings are due for scheduled replacement, proceed as follows:

1) If the monitoring system incorporates a digital data acquisition system, provide the proper status information indicating that maintenance is being performed and that the data must not be entered into the monitored data base. Record the date and time (*Local Standard Time*) that the data channels were marked off-line in the "Comments" section of the Routine Site Check and in the site logbook entry for that day, providing a precise time reference for data review personnel.

2) Accessing Tower-Mounted Sensors:

   If the meteorological tower is of the hinged, fold-down type, refer to Step a) below for accessing tower-mounted sensors. If the meteorological tower does not fold down, refer to Step b) below for accessing tower-mounted instruments.

   (a) For hinged, fold-down towers:

   Carefully unbolt the tower base legs assembly to fold the tower down. The tower is hinged to pivot on two of the base legs. (Depending on the strength of the individual, this procedure may require two people). Leave one bolt in place (slightly loosened) on each of the two base legs which comprise the "hinge" for tower fold-down. These are the two legs closest to, and parallel with, the monitoring compound gate. The two bolts that secure the third leg of the tower to the base assembly should be completely removed.

   The design of the monitoring station compound ensures that the tower will fold down past any obstruction (e.g., through the gate of security fencing, etc.). The tower should be lowered slowly. With arms raised and holding the vertical uprights, slowly "walk" the tower down. Care should be taken that enough slack exists in the signal cables to allow for fold-down prior to engaging in this activity. A box or prop should be placed such that the tower top is supported off the ground when fully folded-down. Care must also be taken to ensure instruments do not strike the ground or are otherwise damaged.

(b) For Non-Folding Towers:

The operator must be trained and qualified to climb the tower to access the tower-mounted instruments. Tower-climbing activities are performed only when weather conditions are suitable (NEVER climb during threat of thunderstorm activity) using OSHA-approved climb safety suspension belts or harnesses equipped with OSHA-approved lanyards and clips for securing the climber safely to the tower. The proper use of this equipment permits the operator to have both hands free for working with the tower-mounted instruments and using hand tools. Enviroplan Consulting routinely trains qualified network operators in the proper procedures and methods for tower-climbing and related activities.

3) Remove the sensor cups assembly by loosening the two top set screws (where the cup arms join the hub) that hold the assembly to the shaft. Lift the cups assembly off the sensor body.

4) Remove the sensor by loosening the two set screws at the base of the sensor. Be careful not to loosen the sensor mounting socket screws located on the crossarm by mistake! (Reference a spare sensor if in doubt.)

5) Hold the sensor in an upright position and gently flick the top hub adapter of the sensor. Closely observe its rotation, especially as it coasts to a stop, to determine if the bearings have acceptably low friction. The hub normally spins freely, slowly decreasing in rotational velocity as it coasts to a smooth stop. An abrupt stop is indicative of excessive friction. Another test of bearing wear is to re-attach the cups assembly and take the sensor to an indoor area that is free of any air movement. While holding the sensor body in a horizontal position (parallel to the ground), slowly rotate the sensor body while observing the cups. There should be no discernible movement of the cups for a complete rotation of the sensor body in both directions if the internal friction is within specification. If the sensor satisfactorily passes this test, the starting torque threshold may be assumed to be <0.2 gm-cm.

   NOTE: A torque watch is the preferred method for measuring sensor starting torque threshold, but is not always practical, due to the very low values involved (typically less than 0.1 gm-cm). If available, a Waters Model 366-3M certified torque watch may be used to assess the starting torque threshold of the Climatronics F-460 wind speed sensor. This torque watch, which has a torque measurement lower limit of 0.2 gm-cm, should register no measurable torque reading if the sensor's starting torque is satisfactory.

6) Evaluate the torque test results and the circumstances which occasioned the test to determine the need for further action and appropriate method of documenting the test results.

a) <u>If sensor starting torque test is performed in conjunction with a scheduled performance audit</u>: Record the "As Found" torque test result in the space provided on Form 10-2. Ensure all "As Found" system performance tests outlined in Section 10.2.1 of this document are completed. If the "As Found" sensor torque test result exceeds the acceptability limits stated in Step 5 above, or if the sensor bearings have accumulated 6 months of use, perform maintenance on the sensor as described in Step 7 below.

b) <u>If the torque measurement is performed in conjunction with investigative actions (i.e., an unsatisfactory routine system check</u>): Evaluate the torque measurement for acceptability (see Step 5 above). If the torque test results are unacceptable, or if the sensor bearings are due for scheduled replacement (i.e., 6 months of cumulative use has accrued since they were new), proceed as instructed in Step 7 below.

If the torque test result obtained in Step 5 above indicates that the bearings and internal friction are acceptable, investigate for further causes of the rotation problem; intermittent binding of an internal moving part may be the reason. Note that the sensor's response threshold is ≤ 0.2 m/s. If the lack of cup rotation is due to dead calm wind conditions, then the sensor's performance may be normal.

If a problem is identified, develop and implement a plan of action to restore the monitoring system to normal operation in as short a time as possible. Perform complete "As Found" and "As Left" system performance tests both prior to and following corrective maintenance as outlined in Section 10.2.1 of this document.

7) Wind speed sensor bearing replacement in the field can be effectively accomplished by either of two methods:

a) Replacement of the entire sensor with a pre-tested spare sensor equipped with new bearings; or

b) Disassembly of the existing sensor accompanied by removal of the old bearings and installation of new bearings. Consult the Climatronics P/N 100075 Wind Speed Transmitter Section or the Climatronics P/N 102236 Vertical Component Anemometer in the Climatronics Engineering Manual for instructions on replacing the sensor bearings.

Wind speed system and sensor performance checks should be performed as soon as practical in conjunction with sensor or bearing replacement. These checks document the system performance both prior to the maintenance ("As Found" tests) and after the maintenance is completed ("As Left" tests). If the maintenance method involves sensor replacement (as in 7-a above), both sensors should be tested. For an emergency swap-out, these tests can be performed at a later, more convenient date. If the original sensor is to be serviced and re-installed (as in 7-b above), then the performance tests should preferably be conducted at the time the maintenance takes place. Refer to Section 10.2.1 in this document for instructions on performing system performance tests. The test data must be documented in the site logbook and on Form 10-2, in accordance with the procedures outlined in Section 10.2.1.

7.1.2 Other Wind Speed Sensor Problems and Associated Corrective Maintenance

If there is no wind speed signal output, this condition may or may not be caused by sensor failure. The following procedure assumes the wind speed sensor appears intact, and the cups assembly is spinning freely.

1) Reference the system interconnection schematic in the Climatronics Engineering Manual and, using a voltmeter, measure and verify the presence of the +12 volts D.C. supply voltage for the sensor at the barrier terminals located on the front of the data logger. If this sensor operating voltage is absent, the problem is likely to be in the Campbell Scientific CR1000 data logger; proceed to Section 7.3 below for information regarding data logger maintenance.

2) If the +12V D.C. supply voltage for the sensor is present, check for the presence of the wind speed sensor output signal at the appropriate terminals on the data logger rear panel barrier strip. (Again, reference the system interconnection schematic in the Climatronics Engineering Manual). The sensor output signal is a square wave whose amplitude is approximately 1.5V peak-to-peak, and whose frequency is proportional to the wind velocity.

3) If the sensor output signal is present, a fault with the data logger is again indicated (refer to Section 7.3 below). If the sensor output signal is absent, provide the appropriate system status information to the DAS and access the tower-mounted sensor as described in Section 7.1.1, Steps 1 through 3, above. Reference the Climatronics Engineering Manual for the crossarm wiring schematic and test for the presence of the 12V D.C. sensor supply voltage at the sensor mounting socket connection on the crossarm. If the supply voltage is present, then the problem is likely in the circuitry in the sensor. If the sensor supply voltage is absent, then the signal cable connecting the data logger to the crossarm (or the crossarm wiring itself) is suspect.

4) Using conventional signal-tracing techniques, continue to investigate to locate the point in the chain of interconnected components at which either of the two signals (i.e., sensor supply voltage or sensor output signal) are no longer present. Proceed to repair or replace the indicated faulty component (sensor, crossarm wiring, or signal connecting cable). Contact the field supervisor or Enviroplan Consulting project manager for technical support and/or spare parts as necessary for prompt resolution of the problem.

5) Follow the instructions in Section 7.1.3, Steps 1 through 4 (below) for restoring the system to normal operation and providing proper documentation of the event after

repairs are completed. If the corrective maintenance required repair or replacement of the wind speed sensor, refer to Section 10.2.1 in this document and perform wind speed system performance tests on the system at the earliest opportunity. Ensure all documentation is complete, including annotating the event and all investigative and corrective actions in the chronological site logbook. The event must also be fully described in a Non-Conformance/Corrective Action (NC/CA) Report (refer to Section 9.3 in this document for guidelines on NC/CA Reports). A reference to the NC/CA report and/or a concise summary of the event should also be made in the "Comments" section of Form 6-1 (Routine System Checks) and/or Form 10-2 (Wind Speed System Performance Tests.

7.1.3 System Restoration

1) When replacing the cups assembly or propeller and the sensor on the crossarm, do not over-tighten the set screws; moderate tightening is sufficient to ensure rigid and secure sensor mounting attachment. Reference Section 7.1.1 (above) and reverse Steps 1 through 4 for re-assembly and restoration of the monitoring system.

   Check the crossarm position for any visible evidence of change from its normal orientation to true north. (Note: The crossarm's orientation is rigidly fixed. Any disturbance of crossarm alignment would require considerable force applied to the structure). If the crossarm orientation is disturbed, the fact should be immediately noted, documented, the field supervisor or Enviroplan Consulting project manager contacted, and an appropriate plan for corrective actions developed and implemented. See Section 2.3 of this document for instructions and procedures for crossarm alignment. If any wind direction data is collected while the crossarm orientation is suspect, an "as found" and "as left" check of crossarm orientation error must be performed and documented.

2) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that valid data is again being collected. Record the date and time (*Local <u>Standard</u> Time*) that the data channel(s) were returned on-line in the “Comments” section of the Routine Site Check Form and in the site logbook entry for that day.

3) Always record all preventive maintenance and corrective maintenance work performed in the chronological site logbook, and on Form 6-1. If Form 10-2 was used in conjunction with performance tests on a failed or suspect sensor, explain the reason for the unscheduled system performance test in the "Comments" section of this form.

4) If the defective sensor was not repaired and tested in the field, securely pack the sensor, protectively wrapped and padded, and ship it to Enviroplan Consulting, NJ. The sensor will be repaired and tested prior to returning it to the field.

7.2 WIND DIRECTION TRANSMITTER

The wind direction transmitter (or "sensor") is engineered for long periods of trouble-free operation in extreme environments. The sensor's calibration is a function of the manufacturer's design, engineering, associated wind tunnel test data and production quality control. The vane assembly does not have to be matched to a particular transmitter, but it must be a Climatronics F460 vane.

The vane assembly is a lightweight, rugged, all metal construction and does not typically require replacement in normal use. If, however, the vane appears damaged (holes, bent, etc.), contact the Enviroplan Consulting project manager for immediate shipment of a replacement vane if no spare is kept on-site.

The weekly routine system checks for the wind direction monitoring system (described in Section 6 of this document) provide frequent verification that the wind direction signal output is representative of prevailing conditions, that the sensor vane rotates freely, and that the sensor and vane are rigidly mounted, plumb and free of damage. Routine preventive maintenance consists of replacing the sensor bearing after six months of cumulative or continuous use. Preventive maintenance is typically performed in conjunction with semi-annual meteorological performance audits following completion of "As Found" system performance tests. "As Left" system performance tests are conducted after maintenance is completed. Refer to Section 10.2.2 in this document for instructions on performing wind direction system performance tests.

Investigative action followed by appropriate corrective maintenance is required if a routine system check or an audit of the system indicates the sensor shaft is not freely rotating (barring calm conditions), or if the vane appears to be damaged, or whenever acceptability limits for system performance tests are exceeded.

7.2.1 <u>Bearing Check and Maintenance Procedure</u>

If a routine system check or performance test of the system indicates the sensor shaft (and vane) is not freely rotating (indicating excessive internal friction), or if the sensor bearing is due for scheduled replacement, proceed as follows:

1) Perform Steps 1 through 3 in Section 7.1.1 (above) to provide proper status indications on the data recording systems and obtain access to the sensor.

2) Remove the vane by loosening the two set screws on the sides of the <u>vane hub</u>. **Do not loosen the set screws on the sensor's keyed vane-mounting hub, which is immediately below the vane hub!** The <u>vane hub</u> sits on top of the sensor vane-mounting hub. As a further means of distinguishing between the two hubs, note that the vane shaft protrudes from either side of the vane hub. Lift the vane off the sensor body.

3) With the sensor in a vertical position, check the sensor starting torque using a certified torque watch with a range of 3 to 24 gm-cm (Waters model 366-1M or

equivalent) in both clockwise and counter-clockwise directions. Maximum starting torque in either direction should not exceed 6 gm-cm.

4) Evaluate the torque test results and the circumstances which occasioned the test to determine the need for further action and appropriate method for documenting the test results.

   a) If sensor starting torque measurement is performed in conjunction with a scheduled performance audit: Record the "As Found" torque measurements in the spaces provided on Form 10-3. Ensure all "As Found" system performance tests outlined in Section 10.2.2 are completed. If the "As Found" sensor torque test results exceed the acceptability limits stated in Step 3 above, or if the sensor bearing has accumulated 6 months of use, perform maintenance on the sensor as described in Step 5 below.

   b) If the torque measurement is performed in conjunction with investigative actions (i.e., an unsatisfactory routine system check): Evaluate the torque measurements for acceptability (see Step 3 above). If either the torque measurement is unacceptable, or if the sensor bearing is due for scheduled replacement, proceed as instructed in Step 5 below.

   If the torque measurements are acceptable, investigate further to determine if there is intermittent binding of the sensor's moving parts or some other assignable cause of the perceived restricted vane movement. Place the sensor (with outer cover removed and vane installed) in a vertical position where it can respond to light wind currents and can be closely observed. Note that the sensor's response threshold is 0.5 mph. If the lack of vane movement is due to calm wind conditions, then the sensor's performance may be normal. Remove the vane and determine whether it is balanced at the hub attachment point. If not, the vane hub can be re-positioned on the vane shaft as necessary to ensure the vane is balanced at its attachment point. Consult with Enviroplan Consulting's or the manufacturer's technical support staff if necessary.

   If a problem is identified, develop and implement a plan of action to restore the monitoring system to normal operation in as short a time as possible. Perform complete "As Found" and "As Left" system performance tests both prior to and following corrective maintenance as outlined in Section 10.2.2.

5) Wind direction sensor bearing replacement in the field can be effectively accomplished by either of two methods:

   a) Replacement of the entire sensor with a pre-tested spare sensor equipped with a new bearing; or

b) Disassembly of the existing sensor accompanied by removal of the old bearing and installation of a new bearing.

It should be emphasized that, unlike the wind speed sensor, the wind direction sensor requires precise internal re-alignment of the keyed vane hub with the potentiometer wiper position to ensure proper azimuth response following bearing replacement. A Climatronics azimuth linearity test fixture (P/N 101754) must be utilized to accomplish this alignment. If replacement of the bearing in the original sensor is performed, consult the Climatronics P/N 100076 Wind Direction Transmitter Manual for instructions on replacing the bearing and properly aligning the vane hub with the potentiometer wiper. The System Performance Test procedures outlined in Subsection 10.2.2 of this document must be performed both before ("As Found" tests) and after ("As Left" tests) sensor bearing replacement. When maintenance and performance tests are complete, proceed to 7.2.3 below.

7.2.2 <u>Other Wind Direction Sensor Problems and Associated Corrective Maintenance</u>:

1) <u>Open fuse in the sensor</u>: This condition will result in a non-varying sensor voltage output equivalent to 360^o. Replace the 1/32 amp fuse using a hemostat or other suitable heat sink between the fuse and the solder-on pigtail leads. Perform complete system performance tests as outlined in Section 10.2.2 at the earliest opportunity following repair.

2) <u>Open potentiometer in the sensor</u>: This condition will also result in a non-varying DAS voltage input equivalent to 360^o. Replace the potentiometer and align the keyed sensor vane mounting hub with the potentiometer wiper position using the Climatronics P/N 101754 azimuth linearity test fixture and following the instructions provided in the Climatronics P/N 10076 Wind Direction Transmitter Manual, or replace the damaged sensor with a pre-tested spare and return the damaged sensor to Enviroplan Consulting for repair and alignment. Perform the "as left" system performance tests outlined in Section 10.2.2 on the restored system at the earliest opportunity.

7.2.3 <u>System Restoration</u>

1) When replacing the sensor and vane assembly on the crossarm, do not over-tighten the set screws; light pressure is sufficient to ensure rigid and secure attachment. Perform Steps 1 and 2 in Section 7.1.1 (above) in reverse order for restoration of the tower and sensor.

   Check the crossarm position for any visible evidence of change from its normal orientation to true north. (Note: the crossarm orientation is rigidly fixed; any disturbance would require considerable force applied to the structure). If the crossarm orientation is disturbed, the fact must be immediately noted, documented and the Field Supervisor or Enviroplan Consulting Project Manager contacted for determination of corrective actions. See Section 2.3 in this document for instructions and procedures for crossarm alignment. If any wind direction data is collected while the crossarm orientation is suspect, "As Found" and "As Left" checks of the crossarm orientation must be performed and documented.

2) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that valid data is again being collected. Record the date and time (*Local <u>Standard</u> Time*) that the data channel(s) were returned on-line in the “Comments” section of Form 6-1 and in the site logbook entry for that day.

3) All preventive and corrective maintenance work should be recorded chronologically in the site logbook and concisely summarized in the "Comments" section of Forms 6-1 and Form 10-3 (if applicable). A Non-Conformance/Corrective Action (NC/CA) Report is required for documenting any problems found and the corrective actions taken to resolve the problem. The NC/CA report should reference the documented "As Found/As Left" performance test results as applicable. Refer to Section 9.3 in this document for guidance on NC/CA Reports.

4) If the defective sensor was not repaired and tested in the field, securely pack the sensor, protectively wrapped and padded, and ship it to Enviroplan Consulting, NJ. The sensor will be repaired and tested prior to returning it to the field.

7.3 TEMPERATURE AND TEMPERATURE DIFFERENCE SENSORS

Temperature sensors are basically maintenance-free. Preventive maintenance is concerned mainly with the housing (aspirated radiation shield). The air passageways and external surfaces should be cleaned at least semiannually. Should excessive dirt necessitate dismantlement of the radiation shield for thorough cleaning, proceed as follows:

1) Provide the proper status indications to the data recording systems as described in Step 1 of Section 7.1.1 (above).

2) Disconnect the A.C. power to the radiation shield. Also disconnect the A.C. power and signal connectors on the shield itself.

3) Looking into the open end of the shield cylinder, you will notice an inner shield assembly with a protruding ring.

4) Gently pull on the ring and slide the inner shield assembly out of the cylinder about 2-3 inches.

5) Un-loop the sensor cable from the inner shield assembly guides. The sensor cable is looped around one of the shield guides that space the inner shield from the outer shield. Remove the entire inner shield.

6) You will notice a thumbscrew at the rear of the inner shield assembly. Loosen the thumbscrew and remove the probe from the inner shield.

7) The inner radiation shield assembly can now be cleaned.

8) Clean the exterior of the radiation shield to ensure effective shielding from solar radiation effects.

9) Unlatch and remove the blower motor housing cover at the rear of the shield. Inspect the aspirator fan blades and barrier strip terminals for the temperature probe signal wiring connections. Remove any accumulated dirt using a stiff brush.

10) To reinstall the sensor, perform Steps 2-6 in reverse order.

11) Provide the proper status information to the data recording systems to indicate that valid data collection has resumed in accordance with the instructions contained in Section 7.1.3, Step 2 (above).

Always record all preventive maintenance performed in the chronological logbook and on Forms 6-1 and Form 10-4 (if applicable).

7.4 SOLAR RADIATION SENSOR

Refer to Section 3.1.7 in this document for a description of the solar radiation sensor.

7.4.1 Preventive Maintenance

Preventive maintenance for the solar radiation sensor consists of: 1.) periodic cleaning of the hemispheric glass dome that surmounts the thermopile; and 2.) replacing the desiccant when the color indicates it is spent. The recommended minimum frequency for performing the cleaning maintenance is weekly, however, more frequent cleaning may be indicated if operating environment factors such as oily aerosols or high particulate concentrations degrade the sensor's performance characteristics. The frequency of desiccant replacement is largely dependent upon prevailing conditions of atmospheric moisture; however, if the desiccant requires replacement more frequently than once per week (as indicated by a change of color from blue to white or pink), it may indicate that the sensor's seals are compromised, requiring corrective maintenance. Unsatisfactory results of routine system checks and/or system performance tests should be considered as possible indicators for more frequent maintenance.

7.4.1.1 Cleaning the Glass Dome

1) Provide the necessary status indications for the data recording instruments (i.e., data logger) in accordance with the directions set forth in Section 7.1.1, Step 1 (above).

2) Use a soft, lint-free cloth to gently wipe away any dust or other foreign material that is visible on the surface of the glass dome. If the material cannot be removed with a dry cloth, a non-abrasive cleaning agent may be used (e.g., a glass cleaning solution), however, the dome should be rinsed with distilled water and dried following the use of

any cleaning agents. It is imperative that the operator **refrain from using any materials that could scratch or alter the characteristics of the precision-ground glass dome**, as this could adversely affect the measurement characteristics of the sensor.

3) After maintenance is complete, the operator should check the sensor's integral spirit level indicator and adjust the level of the sensor (center the bubble in the bull's eye) as necessary.

4) Provide the proper status information to the data recording systems to indicate that valid data collection has resumed in accordance with the instructions contained in Section 7.1.3, Step 2 (above).

7.4.1.2 Replace Color-Indicating Desiccant

If a check of the color-indicating desiccant (visible through the round glass viewing port on the side of the sensor body) reveals that the desiccant is nearly all white or pink, the desiccant should be replenished as follows:

1) Provide the necessary status indications for the data recording instruments (i.e., data logger) in accordance with the directions set forth in Section 7.1.1, Step 1 (above).

2) Unscrew the knurled knob that surrounds the desiccant viewing window and gently pull the cylindrical desiccant chamber straight out from the body of the sensor. (Note: if precipitation is occurring, temporarily disconnect the sensor signal cable connector and remove the sensor to an indoor location to perform this maintenance).

3) Dispose of the spent desiccant and re-fill the chamber with fresh color-indicating desiccant (8~12 mesh color-indicating silica gel). It should be noted that there are no known exposure or environmental hazards associated with silica gel desiccant; spent desiccant may be disposed of directly in with normal trash. Spent silica gel desiccant may also be recycled for future use by drying it in a conventional oven at ~350^{o}F for 15~20 minutes.

4) Re-install the desiccant chamber into the sensor body by reversing Step (b) above. Hand-tighten the knurled knob of the desiccant chamber assembly and ensure it is fully seated against the gasket and sensor body.

5) After maintenance is complete, the operator should check the sensor's integral spirit level indicator and adjust the level of the sensor (center the bubble in the bull's eye) as necessary.

6) Provide the proper status information to the data recording systems to indicate that valid data collection has resumed in accordance with the instructions contained in Section 7.1.3, Step 2 (above).

7.4.2 Solar Radiation Sensor Problems and Corrective Maintenance

The following information is provided to assist the operator in correcting certain user-serviceable problems that can occur from time to time. Great care should be exercised whenever servicing the solar radiation sensor to avoid damaging the glass dome and thermopile elements-even the slightest scratching or marring of these components can irreversibly damage the sensor and seriously alter its performance characteristics. Resolution of more serious problems should be referred to the manufacturer in consultation with the Project Manager.

a) Liquid Moisture Present Within Sensor: Liquid-phase moisture within the sensor will interfere with the transmission of solar energy through the polished glass dome and thermopile's ability to accurately respond to solar radiation energy. Affected data should be considered suspect and are subject to invalidation. Moisture within the sensor's interior may result from a degraded seal between the sensor's parts or from condensation. The latter cause can typically be attributable to insufficient frequency of desiccant preventive maintenance, especially during extended periods of high humidity. If moisture is evident within the sensor, it will have to be carefully dried before representative measurements can again be obtained. The corrective maintenance should be accompanied by investigative actions to determine, if possible, the time that the problem first occurred and an Assignable Cause for the problem. Subsequent actions should be directed to correct any deficiencies to lessen the chance of the problem reoccurring.

   1) Provide the necessary status indications for the data recording instrument (i.e., data logger) in accordance with the directions set forth in Section 7.1.1, Step 1 (above).

   2) Disconnect the sensor's output signal cable from the sensor and remove the sensor from its mount. Transport the sensor to a clean, well-lit, protected environment where it can be inspected, disassembled and serviced.

   3) Visually inspect the sensor for any signs of damage. Carefully examine the area where the sensor's glass dome is fastened to the sensor body for evidence of a poor fit or damaged or mis-aligned seal. Using a hex key, test the fasteners around the perimeter of the dome to see if any are loose. (Note: if the moisture is largely present on the inside surface of the glass dome, the Assignable Cause is most likely condensation, as opposed to a mechanical leak.

   4) Using a hex key, unscrew the fasteners around the perimeter of the glass dome. Carefully remove the glass dome from the sensor body and temporarily put it in a safe place where it won't get scratched or abraded. Use a Kim Wipe or similar lint-free, non-abrading absorbent material to gently blot dry the surfaces of the thermopile elements (do NOT rub or apply pressure to the surface of the thermopile elements!). Clean and dry the interior surface of the dome using a soft, lint-free cloth.

   5) Check to ensure the gasket around the perimeter of the thermopile elements is properly seated and undamaged. Use a pressurized canister of clean, dry air

(commonly available for cleaning electric equipment) to blow away any remaining dust from the interior surfaces of the sensor just prior to re-assembly.

6) Re-assemble the sensor by installing the fasteners removed in Step 4 above. Employ even-tightening technique during re-assembly. Visually inspect the interior surfaces of the sensor (under the glass dome) to confirm there is no dust or foreign material inside prior to final tightening of the fasteners.

7) Replace the desiccant (refer to the procedure in Section 7.1.4.2 above).

8) Re-mount the sensor (ensure it is level) and re-connect the signal cable. Check the instantaneous solar radiation indication on the data logger for reasonableness and agreement with current conditions. If the data appear reasonable and the operation of the measurement system normal, proceed to Step 9 below.

9) If the data appear unreasonable or the measurement system's operation is suspect, double-check the sensor's installation and signal cable connection and correct any faults (the bayonet-type signal cable connector can require significant clockwise force to fully seat and "lock"). If the suspect operating condition persists and the cause of the problem is not visible, reference the system technical manuals and wiring interconnection diagram and use conventional electronic signal tracing techniques to isolate the problem. Contact Enviroplan Consulting's technical support or the manufacturer's service department for assistance as necessary. If the problem cannot be readily resolved, consult with the Project Manager or Field Supervisor and formulate an Action Plan for resolving the problem and restoring the measurement system to normal operational status as soon as practicable. A complete, documented System Performance Test may be warranted following resolution of the problem to formally confirm acceptable system operation (refer to Section 10.2.4 in this document for Solar Radiation System Performance Test procedures).

10) Following completion of the maintenance and confirmation of normal system operational status, provide the proper status information to the data recording systems to indicate that valid data collection has resumed in accordance with the instructions contained in Section 7.1.3, Step 2 (above).

b) Physically Damaged Sensor: The body of the solar radiation sensor is constructed of cast aluminum with a white enamel finish and is not particularly susceptible to physical damage. The ground-glass dome and the thermopile elements are, however, delicate and are vulnerable to physical damage. Physical shock can damage the thermopile without visible evidence. Should the glass dome sustain damage (e.g., breakage, cracking, scratching or marring of any sort), the sensor should be immediately removed from it's mount and carefully inspected for any signs of collateral damage, especially to the thermopile elements. If it appears that the thermopile is undamaged, a replacement dome can be obtained from the manufacturer. Follow the procedure outlined in Step (a) above to install the replacement dome (keep the sensor in a well-protected environment until repairs can be made).

Other damaged mechanical parts can be similarly replaced, however, care should be taken during the course of repair and re-assembly to ensure the integrity of all gaskets and seals.

Any confirmed or suspected damage to the thermopile elements (or internal electronic components) mandates return of the entire sensor to the manufacturer for repair and re-calibration. The Project Manager should be consulted to facilitate making these arrangements. The sensor must be protectively packaged and shipped via a reliable commercial delivery service that provides a shipment tracking number (retained by the operator).

7.5 RELATIVE HUMIDITY SENSOR

Relative Humidity sensors are basically maintenance-free. If the sensor becomes contaminated, it may be gently washed in distilled water or alcohol. It is permissible to clean the sensor in a sonic cleaner. In especially dirty operating environments, the dust cap on the sensor may require periodic replacement (typically once per year, if this is the case). “As found” system performance tests should be completed prior to replacing the sensor dust cap. “As left” system performance tests should also be performed subsequent to this maintenance. Refer to Section 10.2.3 in Part 3 of this document for Relative Humidity System Performance Test procedures.

All other preventive maintenance is concerned with the aspirator shields, as described above in Section 7.3.

Always record all preventive maintenance (PM) performed in the chronological logbook and on Forms 6-1 and 10-5 (if applicable).

7.6 PRECIPITATION GAUGE

Periodically check the rain gauge funnel screen and remove debris that may have collected. The tipping bucket and drain line should be cleaned semi-annually or more frequently if the operating environment conditions warrant. Make sure the buckets and the inner funnel are clean and free from obstructions. The tipping bucket and pivot bearings are hardened high carbon steel, chrome plated, and are treated with a light coating of machine oil. Every six months of operation a drop of light oil should be placed at each pivot point. Vegetation in the immediate area should be kept below a height of 6 inches.

Always record all preventive maintenance performed in the chronological logbook and on Forms 6-1 and 10- 6 (if applicable).

7.7 BAROMETRIC PRESSURE SENSOR

Barometric Pressure sensors are basically maintenance-free. The sensor is housed inside the NEMA 4-X enclosure or monitoring shelter and is protected from dirt and moisture. The sensor has been designed to be inherently stable.

Always record all preventive maintenance (PM) performed in the chronological logbook and on Forms 6-1 and 10-5 (if applicable).

7.8 DIGITAL DATA ACQUISITION SYSTEM

The data logger is a solid-state electronic device which requires little or no preventive maintenance. Refer to Part 3, Section 4 for an Overview of Care and Maintenance of the data logger or to the Manufacturer’s Engineering Manual for the Campbell Scientific CR 1000 Data logger for information and procedures for resolving data logger problems.

8. DATA RECORDING, REDUCTION AND VALIDATION

This section presents the methodologies employed for the reduction, processing and validation of meteorological data. All system outputs except precipitation data are recorded as one minute and hourly block averages on a digital data acquisition system (DAS). The DAS reports precipitation in hourly block values representing the total precipitation in inches per hour. Periodic system checks and test results documented on field quality control check forms and audit forms are also integral to the data validation process.

8.1 DATA TRANSMISSION, REVIEW AND STORAGE

8.1.1 Purpose and Scope

The purpose of this procedure is to provide documentation and instruction for the receipt and storage of monitoring data from remote stations by the Data Management Department.

8.1.2 Frequency

One minute and hourly digital data is collected daily (automatically). These data are stored in battery-protected SRAM and also in removable flash memory, thereby preventing data loss in the event of a power outage. The data logger will be equipped with sufficient flash memory to store approximately one year of data.

8.1.3 References

- Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurement Systems, EPA-454/B-08-002, March 2008;

8.1.4 Equipment and Materials

Equipment used is a dedicated Data Management Department personal computer (PC) equipped with a modem and running Campbell Scientific "LoggerNet" communications, data processing and reporting software.

8.1.5 Procedure: Data Transmission and Storage

8.1.5.1 The PC is programmed to connect via an internet connection all ambient monitoring stations operated by Enviroplan that use a Campbell Scientific-brand data logger (DAS).

8.1.5.2 Automatic interrogations are performed daily between 1:00 A.M. and 7:00 A.M. during which time each station's DAS is requested to transfer all requested information (usually a daily summary providing yesterday's data as 1-minute and hourly values for each measured parameter plus quality control information).

8.1.5.3 Each business day a data technician checks the PC data files to ensure that all data were successfully transmitted and stored in the PC. If all data were not successfully transmitted, the technician will manually attempt to contact and interrogate the on-site data logger to retrieve the data. If this attempt is unsuccessful, the field supervisor and local network operator are notified and advised to investigate and resolve the problem as soon as possible.

Data are also reviewed for reasonableness and completeness. (See Table 1-2 in Section 1 of this document for completeness criteria and goals). The data technician will annotate the hard copy data summary report printout summarizing any suspect operating conditions or unreasonable data values. The field supervisor (or project manager) and the local network operator will be immediately contacted to investigate and resolve any suspect or uncontrolled operating conditions.

8.1.5.4 Data review shall occur no more than four days after sample acquisition because of weekends and holidays.

8.1.6 Restoration

Ensure all documentation is complete.

8.1.7 Documentation

Hard copy printout of daily data summary reports, (including annotations, if any) archived by the Data Manager.

8.2 DATA REDUCTION PROCEDURES

8.2.1 General Requirements

8.2.1.1 Purpose and Scope

The purpose of this procedure is to provide documentation and instruction for reducing meteorological data according to standard methodologies.

8.2.1.2 Frequency

Data are reduced on a monthly basis.

8.2.1.3 References

Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurement Systems, EPA-454/B-08-002, March 2008;

8.2.1.4 Equipment and Materials

None

8.2.1.5 Procedure

a) The basic reduced data are averaged over a period of 1 hour. Precipitation data, however, are the summed (total) precipitation for each hour.

b) At least 45 minutes of valid data during each hour must be available to report a 1-hour average.

c) Each averaging period is identified by the beginning-time of the period.

d) Time must always be reported as local standard time.

e) On a (minimum) monthly basis, all documentation for field quality-control checks performed in the previous month is shipped to Enviroplan Consulting's Data Management Department in Wayne, NJ. The digital data (which are automatically polled each day) are reviewed for validity and reasonableness via comparison against documented quality control (QC) check results, routine site check results, and any Non-Conformance/Corrective Action (NC/CA) Reports, relevant audit and/or System Performance Test results.

f) An accounting of all hours is made, with any missing data appropriately designated. Any hours incorporating a test, calibration, maintenance or preventive maintenance that adversely affect the data, as well as data deemed invalid due to a known, well-documented cause (e.g., sensor malfunction, power outages, etc.) are removed from the data set and replaced with EPA-designated null data codes. In all cases, any hour removed from the data set, for any reason, must be substantiated with a well-documented reason.

g) Data losses greater than six consecutive hours will be documented by the network operator in the site logbook, and on the routine site check form (Form 6-1). Also, a Non-Conformance/Corrective Action Report Form must be completed (See Section 9.3 in this document).

h) All meteorological parameters except precipitation, vector-averaged horizontal wind direction, vector-averaged horizontal wind speed and the standard deviation of the wind direction (sigma theta) are calculated from the instantaneous sample values using arithmetic (scalar) averaging functions resident in the Campbell Scientific data logger firmware.

i) Vector-averaged horizontal wind direction and vector-averaged wind speed are calculated internally by the data logger using the instantaneous sample values (1-second sample rate) and an EPA-approved vector averaging algorithm.

j) Sigma theta is calculated internally by the on-site data logger based on 900 instantaneous wind speed and wind direction values sampled every 15 minutes. The four resulting 15-minute sigma theta values are then averaged by the data logger to produce the hourly-averaged sigma theta value.

k) Wind direction data are reported in degrees of azimuth (^{o}) from true north resolved to the nearest whole value using conventional arithmetic rounding conventions. All horizontal wind direction averages indicating true north are reported as 360 degrees, not 0 degrees.

l) Wind speed data are reported in meters per second (m/s) and are resolved to the nearest tenth using conventional arithmetic rounding conventions.

m) For hours during which the average horizontal wind speed is less than 0.45 m/s (1.0 mph), both the wind speed and corresponding wind direction data are designated as "calm".

n) Temperature and temperature difference (Δ-T) data are reported as hourly block-averages scaled in degrees Celsius (°C) resolved to the nearest tenth using conventional arithmetic rounding conventions.

o) Relative humidity data are reported as hourly block-averages scaled in percent (%) resolved to the nearest tenth using conventional arithmetic rounding conventions.

p) Barometric pressure data are reported as hourly block-averages scaled in millibars resolved to the nearest whole value using conventional arithmetic rounding conventions.

q) Solar radiation data are reported as hourly block-averages in watts per square meter (W/m^2) resolved to the nearest whole value using conventional arithmetic rounding conventions.

r) Precipitation data are calculated internally in the on-site data logger and are reported as hourly block values representing the total (arithmetic sum) precipitation for that hour in inches resolved to the nearest hundredth of an inch using conventional arithmetic rounding conventions.

8.2.1.6 Restoration

Be sure all documentation is complete.

8.2.1.7 Documentation

- Hard copies of raw data downloaded from on-site DAS (with annotations, as applicable).
- Hard copies of reduced data from data processing software output (with annotations, as applicable).

8.3 DATA PROCESSING PROCEDURES

8.3.1 Purpose and Scope

The purpose of this procedure is to provide documentation and instruction for processing data collected via the PC and Campbell Scientific "LoggerNet" software to be prepared for reporting.

8.3.2 Frequency

Data are processed on a monthly basis.

8.3.3 References

- Data Processing Manual (Air Quality Monitoring Division); and
- Campbell Scientific "LoggerNet" User Manual.

8.3.4 Equipment and Materials

A personal computer (PC) located in the Enviroplan Consulting Data Management Center running the following software:

- Campbell Scientific "LoggerNet" proprietary data processing and reporting software.
- Microsoft Excel tm or other commercially available spreadsheet-type software.

8.3.5 Instructions

8.3.5.1 Within the first ten working days of each month, a data technician will access the digital electronic file of raw data collected at one monitoring station during the previous month and develop an initial data report, which is subsequently reviewed by the data technician for completeness.

8.3.5.2 The initial hard copy data report is then reviewed by the Data Manager or trained data technician and corrections/additions are made as needed. This review consists of comparing the data against the field documentation and corresponding raw data to identify periods of missing or non-representative data, as defined by anomalous or uncharacteristic patterns, any suspect or unsatisfactory instrument operating status indications, out-of-control QC check results, calibration and audit results, or other significant events (e.g., power outages at the site or instrument maintenance, etc.).

8.3.5.3 Review of raw data includes all 1-minute data recorded during the reporting period for each parameter. The 1-minute data are reviewed as scaled time-series values graphically displayed on a PC monitor using the LoggerNet software. This review is analogous to review of continuously-recorded strip chart data, inasmuch as anomalous or erratic values of short-term duration are more readily identifiable. Periods of suspect time-series data are subjected to additional scrutiny and evaluated for possible monitoring system fault conditions or unusual events during the data validation process (refer to Section 8.4 below).

8.3.5.4 Based on the preceding review, the initial hard copy data report is annotated for any required corrections by the data technician. It is submitted to the Data Manager or her designee, who will enter any indicated corrections into the data processing file or flag suspect data for further review. (Note: the original, uncorrected raw data file cannot be altered and is retained and archived).

8.3.5.5 A new hard copy of the corrected data report is generated and provided to the data manager or designated data technician for further review and to verify any corrections made to the data processing file.

8.3.5.6 Steps 8.3.5.2 thorough 8.3.5.5 are iterative until the Data Manager receives a report that is initialed as "ready for QA review".

8.3.5.7 The "ready for QA review" data report is then given to the Quality Assurance Section for review. (See Section 8.4 for data validation procedures).

8.3.5.8 After review, any further corrections, and final approval of the data by the Quality Assurance Section, the final monthly data are made available for submittal to the client and/or agency charged with oversight authority for the monitoring program in the approved data reporting format.

8.3.6 Restoration

None

8.3.7 Documentation

Initial, all intermediate and final hard copies of data reports (with annotations, as applicable), signed and dated by relevant Data Management Department personnel and quality assurance personnel, returned to the Data Manager for archival.

8.4 METEOROLOGICAL DATA VALIDATION

This section presents the procedures used to validate meteorological data. These procedures are handled completely independent of initial data collection. The Data Manager is responsible for ensuring that all data is validated before release.

8.4.1 Purpose and Scope

The purpose of this procedure is to provide documentation and instruction to ensure that all hourly data is verified as being valid before it is released. The purpose of data validation is to detect and remove from the reported data any values inconsistent with Measurement Quality Objectives (MQOs) established for the monitoring project (presented in Table 1-4 in Section 1 of this document) and by extension, data that are not representative of actual meteorological conditions at the monitoring station.

Data validation procedures are handled completely independent of initial data collection activities. Personnel responsible for data validation are not directly involved with data collection.

8.4.2 Frequency

Routine data validation is performed on a monthly basis.

8.4.3 References

- Historical data sets
- Raw, all intermediate and "ready for final" meteorological data reports (hard copies).
- Completed Routine Site Checklist forms.
- NC/CA Reports
- Meteorological Audit and/or System Performance Test results.

8.4.4 Equipment and Resources

- All reference materials from Subsection 8.4.3 above.
- PC running Campbell Scientific LoggerNet software

8.4.5 Instructions

8.4.5.1 Hard copies of the processed digital data (with corrections and annotations entered, as applicable) and corresponding digital electronic data files are reviewed by quality assurance personnel for incorrect or suspicious values. A number of objective tests may be applied to the data set during this step, including:

- Gross Limit Checks - Upper and lower limits are developed for each meteorological parameter by examining historical data.
- Parameter Relationship Test- This test involves a comparison between two or more related parameters.

8.4.5.2 A decision is made on whether questionable values are valid. These decisions are reached by:

- Review of Routine System Checklists submitted by the site operator, site logbook entries and previous calibration or system performance test data. This documentation includes information about calibrations, system operational status and monitoring site activities.
- Comparison of the data with corresponding data collected at a nearby monitoring site or by the National Weather Service.
- Consultations with the site field operator regarding monitoring system operations and observations.
- The field operator may be instructed to perform an "As Found" system performance (unadjusted calibration) test as described in Section 10 in this document the resulting test data evaluated for conformance with acceptance criteria. The "As Found" calibration test data may support correcting affected data for bias based on a quantifiable, linear correlation relationship between Expected and Observed calibration test values.

- In the event that an intermittent fault condition is identified, affected data values may be selectively invalidated (and unaffected values validated for reporting) if it can be demonstrated that: 1.) Intervals in the data record in which the intermittent fault condition occurred can be clearly and unambiguously differentiated from intervals during which the fault was absent; and 2.) The monitoring system's performance was unaffected for all intervals in which the fault condition was absent. Decisions of this nature require documentation of Investigative Actions in the field and identification of an Assignable Cause of the intermittent fault as well as consultations with technical staff familiar with the instrument.

8.4.5.3 The QA reviewer provides any further corrections and revisions made as a result of the above steps with supporting documentation to the Data Manager or designee. These corrections and revisions are then integrated into the data files and the data reprocessed.

8.4.5.4 The final printouts are then checked against the annotated, previous data files to ensure that any corrections and revisions were correctly made. The final printout is then signed "Ready for Final" by the Data Manager, and the data are then released for inclusion in the data report.

8.4.6 Restoration

Ensure all documentation is complete

8.4.7 Documentation

The Data Manager will be responsible for archiving the data, which include:

- All meteorological monitoring program field documentation.
- All meteorological monitoring program data hard copies (including raw data logger data, summary reports and annotations, as applicable).

9. DATA REPORTS AND NON-CONFORMANCE/CORRECTIVE ACTION REPORTS

9.1 METEOROLOGICAL DATA REPORTS

9.1.1 Interim Data Reports

Upon request received from the client or its assigns (e.g., a designated consultant), Enviroplan Consulting will prepare and submit an Interim Data Report consisting of tabular listings of hourly and/or 1-minute data averages of all meteorological parameters collected during a time interval defined by the client or its assigns.

Interim Data Reports will be electronically transmitted to the client or its assigns via email as soon as practicable following receipt of the report request. The submitted data will be formatted as tabular data listings with date and time fields in an electronic digital spreadsheet file (i.e., Excel tm). Data that have been fully processed and validated will be identified. Data that have yet to be processed and validated will also be identified.

9.1.2 Quarterly Data Reports

Quarterly data reports will be submitted to the client within 45 days following the end of each quarterly reporting period as an electronic digital spreadsheet file (i.e., Excel tm). A CD ROM containing the data report will be provided upon request. Quarterly Data reports will include summary listings of hourly data values collected for each meteorological parameter during the calendar quarter reporting period. EPA Aerometric Information Retrieval System (AIRS) reason codes will be entered in any field representing missing or invalidated data values.

Quarterly data reports will include:

- Meteorological data summaries on a monthly basis.
- A quality assurance (QA) report consisting of relevant calibration results, data recovery rates and explanations of missing data periods, and results from independent performance and systems audits.
- horizontal wind speed measurements as tabular, hourly block-averaged data reported in meters per second (m/s) rounded to the nearest tenth of a mph.
- horizontal wind direction measurements as tabular, hourly block-averaged data reported in degrees of azimuth rounded to the nearest whole degree.
- sigma theta measurements (i.e., the standard deviation of the wind direction) as tabular, hourly block-averaged data reported in degrees.
- vertical wind speed measurements as tabular, hourly block-averaged data reported in meters per second (m/s) rounded to the nearest tenth of a mph.

- sigma W measurements (i.e., the standard deviation of the vertical component of wind speed) as tabular, hourly block-averaged data reported in mph.

- ambient air temperature and temperature difference measurements as tabular, hourly block-averaged data reported in degrees Farhenheit (^oF) rounded to nearest tenth of a degree.

- Relative humidity measurements as tabular, hourly block-averaged data reported in percent (%) rounded to the nearest whole percent.

- Precipitation measurement data reported as tabular, hourly inches of rainfall rounded to the nearest one-hundredth of an inch.

- Solar radiation measurements as tabular, hourly block-averaged data reported in watts per square meter (W/m^2) rounded to the nearest whole W/m^2.

- Barometric pressure measurements as tabular, hourly-block-averaged data reported in millibars (mb) rounded to the nearest whole mb.

Monthly and quarterly data recovery rates and explanations of missing data periods will also be summarized. The results of monitor performance checks will be included and discussed with respect to their conformance with applicable accuracy objectives. Finally, the report will contain copies of the various quality assurance check forms completed during the current reporting period (i.e., calibrations and independent performance and systems audits).

9.2 NON-CONFORMANCE/CORRECTIVE ACTION REPORTS

A Non-Conformance/Corrective Action (NC/CA) Report should be produced in the event of any deviation of operations or performance of any instrument which may affect the validity of data being collected by the monitoring system. This includes calibration equipment, data acquisition systems, etc. <u>Some</u> examples of events warranting an NC/CA report are:

- Established control limits for QC checks exceeded (Refer to Tables 1-2, 1-3 and 4-1 in this document);
- Monitoring equipment and/or support equipment malfunctions;
- Improper procedures used during calibrations or operations;
- Power outages of more than a few minutes duration; and
- Missing or insufficient data documentation.

NC/CA reports may be generated by any member of the project team shortly following discovery of a problem or suspected problem. NC/CA reports are generated as an email with a distribution list that includes each project team member. At a minimum, the distribution list will include the Project Manager, the Data Manager, the Quality Assurance Coordinator, field supervisory personnel, the Field Operator and all data technicians.

When a NC/CA report is first generated, the Field Operator is typically instructed by a senior project team member to make an unscheduled emergency maintenance visit to the affected monitoring site to investigate the problem, determine an Assignable Cause and resolve the problem as quickly as practicable. The Field Operator has sufficient technical skills and knowledge of the monitoring system and instruments so as to be able to perform basic trouble-shooting to identify the fault. Depending on the complexity of the problem, the Field Operator may request and receive technical support during this process from a senior Monitoring Engineer.

If the affected instrument is still operational, the Field Operator will perform an “As Found” calibration to characterize and quantify any bias introduced into the measurement system prior to performing any corrective maintenance. The Field Operator will then calibrate the measurement system following completion of any maintenance.

The process of investigating and resolving a Non-Conformance event may require more than a one day. Each time a project team member performs any action or obtains additional information pertinent to the Non-Conformance event, the project team member will update the NC/CA email with a concise summary of the action(s) taken and/or additional information obtained. The project team member will accomplish this update using the “*Reply All*” email function, thereby ensuring continued distribution to all relevant project team members of the updated NC/CA Report. This process is iterative until the Non-Conformance event is fully identified, resolved and associated impact on the data set understood and documented in the NC/CA Report (a single email document).

Each NC/CA email report will include:

- A concise description of the problem;
- Time and date of discovery and who made the discovery;
- Identification of any malfunctioning equipment or monitoring instrument;
- Parameter(s) affected and a preliminary indication of data status (e.g. valid, suspect or invalid);
- Begin and End times and dates of the problem;
- Actions taken to investigate and diagnose the problem;
- Identification of any “As Found” calibration or performance test data obtained prior to implementing corrective maintenance;
- A description of corrective maintenance performed and other actions taken (including calibration) to restore the system to normal operation;
- An assessment of the impact of the NC/CA event on data validity, including any additional data review or validation measures and/or equipment maintenance procedures;
- Identification of individuals who performed the actions taken above;
- An assessment of the impact on network operations and recommendations as appropriate for preventative measures against future recurrence.

NC/CA reports will be reviewed by the Data Management Department and Quality Assurance personnel in conjunction with data review and validation. The field operations supervisor and Project Manager will review NC/CA Reports to confirm final resolution of the problem. The Project Manager will archive each completed NC/CA report in a designated folder in the Local Area Network for the Enviroplan Consulting Monitoring Division.

10. INDEPENDENT METEOROLOGICAL AUDITS AND SYSTEM PERFORMANCE TESTS

Two types of audits will be conducted on the meteorological measurement system: 1) a systems audit (see procedures presented in Subsection 10.1) and 2) a performance audit (see procedures presented in Subsection 10.2) Systems audits provide an independent, qualitative check of the degree to which monitoring program activities conform to the approved Quality Assurance Project Plan (QAPP); how well it is being implemented and how evidence of the network operator's actions is kept. Performance audits provide an independent, quantitative assessment of measurement system and data accuracy.

All audits are performed by personnel who are not associated with the routine calibration and operation of the monitoring system. All calibration test equipment used for an audit is different from that normally used for routine calibrations at the site and is referenced to NIST or other authoritative standards where applicable.

Performance audits are conducted using the system performance test procedures outlined in Subsection 10.2. *These procedures are also utilized to assess system performance in conjunction with corrective maintenance occasioned by sensor failure or malfunction*. Accordingly, Sections 5 (Calibration) and 7 (Preventive and Corrective Maintenance) reference these test procedures for assessing data accuracy when the operational status of the sensors is suspect, or when sensor failure requires repair or replacement.

10.1 SYSTEMS AUDIT PROCEDURES

10.1.1 Purpose and Scope

The purpose of this procedure is to provide documentation and instruction for checking the overall conformance of the meteorological measurement system to the QAPP and the performance of the network operator(s).

10.1.2 Frequency

A Systems Audit will be conducted within 30 days of station start up and at six months intervals thereafter.

10.1.3 References

- Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurement Systems, EPA-454/B-08-002, March 2008;

- Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD), EPA-450/4-87-007, May 1987; and

- Climatronics Corp. System Engineering Manual

10.1.4 Required Equipment and Materials

Form 10-1: Meteorological Systems Audit Checklist (an example of this form can be found at the end of Section 10).

10.1.5 Instructions

a) Check chronological site logbook for dates of Meteorological QC checks performed since the last audit. Make sure that they are being performed on schedule and entered properly in the site logbook.

b) Check chronological site logbook for dates of routine maintenance for each instrument. Make sure that maintenance is being performed on schedule and entered properly in the site logbook.

c) Check chronological site logbook for average frequency of routine system checks. Make sure that they are performed at least once per week and entered properly in the site logbook.

d) If possible, interview the site field operator regarding calibration and maintenance procedures followed.

e) Check exposure of the sensors to see that the system conforms to the siting criteria outlined in Section 2 of this document.

f) Review all documentation for completeness. Ensure that routine site check forms are completed, at a minimum, once per week.

g) Review any recent NC/CA reports that have been completed or are in progress. Note and describe any currently unresolved problems with monitoring system operation. Note and describe if corrective actions have or are being implemented.

h) Complete Form 10-1 and note any problems or observations in comment section. Also note the audit event in the chronological site logbook.

10.1.6 Restoration

Ensure all documentation is complete.

10.1.7 Documentation

Form 10-1: Meteorological Systems Audit Checklist (presented at the end of Section 10).

10.2 METEOROLOGICAL MONITORING SYSTEM PERFORMANCE TEST PROCEDURES

10.2.1 Horizontal Wind Speed System Performance Test

10.2.1.1 Purpose and Scope

The purpose of this procedure is to provide instruction for conducting authoritative tests designed to assess the accuracy and performance of the entire horizontal wind speed monitoring system. This procedure also provides instructions for documenting and evaluating the test results.

Implementation of this procedure by an independent auditor, using equipment other than that normally utilized for routine network operation, constitutes an independent performance audit on the wind speed measurement system. This procedure is also used for assessing the measurement system accuracy when the operational status of the horizontal wind speed sensor is suspect, or when sensor failure requires repair or replacement.

10.2.1.2 Frequency

Performance audits should be conducted at least semiannually following station startup. System performance tests should be performed in conjunction with station startup and also when a problem with the sensor which might affect data accuracy is suspected or confirmed. Refer to Section 7, "Preventive and Corrective Maintenance", in Part 3 of this document for further guidance on conducting system performance tests in conjunction with corrective maintenance on the sensor.

10.2.1.3 References

- Refer to Section 10.1.3 for a listing of references.

10.2.1.4 Test Equipment

- NIST-traceable frequency counter with 0.01 sec/100 Hz resolution and an accuracy of ±1 count □ time base uncertainty.

- Certified variable speed or synchronous anemometer drive motor(s) with an accuracy of ±1 RPM at (minimum) 300 and 600 RPM.

- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).

10.2.1.5 Procedure for Wind Speed System Performance Test

a) Enter start of test (date, time, and initials) on Form 10-2 and in the site logbook. Indicate whether the performance test for wind speed systems is a performance audit or unscheduled system calibration test by checking the appropriate space at the top of Form 10-2. If the performance test is not an audit, explain the reason for the test in the "Comments" section at the bottom of Form 10-2.

b) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that either an audit or system performance test, as applicable, is being performed and that the data must not be entered into the monitored data base. Record the time (*Local Standard Time*) that the data channels were marked off-line in the space provided on the Audit Form(s) and in the site logbook entry for that day.

c) Access the horizontal wind speed sensor. Refer to the instructions provided in Section 7.1.1, Step 2 of this document for accessing the horizontal wind speed sensor on the meteorological tower.

d) Remove the anemometer cup assembly according to the manufacturer's instructions. The complete absence of rotation of the sensor hub and shaft represents dead calm conditions. Record the corresponding DAS response (in engineering units) in the spaces provided in the "As Found" section on Form 10-2 under "System Test Results". Subtract the target response (i.e., 0.3 mph) from the DAS engineering unit response to compute the error (in mph). Record the error in the space provided in the "As Found" section on Form 10-2 under "System Test Results".

e) Attach the certified anemometer drive motor to the anemometer cup shaft to rotate the sensor's shaft at a minimum of two (and preferably three) simulated wind speeds (e.g., 16.3, 32.0, and/or 47.8 mph). Refer to the manufacturer's published transfer function for the wind speed sensor to determine the required rotational rates for simulated wind speeds. (For the Climatronics F-460 wind speed sensor 300 RPM = 16.3 mph; 600 RPM = 32.0 mph and 900 RPM = 47.8 mph).

   The motor should be run until a stable response for each simulated wind speed is obtained. Record the corresponding DAS response (in engineering units) for each simulated wind speed in the spaces provided in the "As Found" section on Form 10-2 under "System Test Results".

f) Subtract the expected (target) value (in m/s) from the DAS response to compute the error for each test condition. Record each error (rounding to the nearest tenth of an m/s) in the spaces provided in the "As Found" section of Form 10-2, under "System Test Results".

g) Perform a sensor bearing torque check as described in Section 7.1.1, Step 5 in this document. Record the torque check result in the "As Found" space provided on Form 10-2. Provide documentation of the bearing replacement date, as well as the next replacement due date, in the "As Found" spaces provided on Form 10-2.

h) Evaluate the sensor starting torque and bearing maintenance status in accordance with the criteria and maintenance requirements described in Section 7.1.1, Step 6.

If preventive or corrective maintenance is required, refer to Step 7 in Section 7.1.1, and follow the procedure for sensor maintenance described in that step. If maintenance consists of sensor replacement, record the replacement sensor serial number (S/N) in the designated spaces provided in the "As Left" sections of Form 10-2. If the original sensor is returned to service following maintenance, record that sensor S/N in the appropriate spaces in the "As Left" sections on Form 10-2.

i) Evaluate the "As Found" System Test Results obtained in conjunction with Steps b and c above with the acceptability limit for measurement system accuracy below:

Acceptability Limit For Wind Speed System Performance Test Results: Wind speed error should not exceed ±0.2 m/s (±0.44 mph).

j) If each of the System Test errors obtained in Step f) above is within the acceptability limits for horizontal wind speed measurement accuracy, and no maintenance or adjustment was required or performed on the sensor following the completion of "As Found" Performance Tests, then proceed to 10.2.1.6 ("System Restoration") below.

k) If any of the System Test errors exceeds the acceptability limits for accuracy stated above, *or* if any maintenance was performed which might affect the performance of the sensor (including replacement of the sensor or sensor bearings), then repeat the System Performance Tests described in Steps d) through h) above and record these test results in the "*As Left*" section on Form 10-2 under "System Test Results".

l) Evaluate all "*As Left*" System Test results by comparing the "As Left" errors with the acceptability limits for accuracy above. If the “As Left” System Test results are within the acceptability limits for horizontal wind speed accuracy, then proceed to 10.2.1.6 ("System Restoration") below. If any error exceeds the acceptability criteria for accuracy, investigate to find the cause of the problem and establish a plan of action to promptly correct the condition. Satisfactory System Test results must be obtained before the problem can be considered successfully resolved and valid wind speed data collection resumed.

10.2.1.6 System Restoration

a) Remove all test equipment utilized in the performance of this procedure.

b) Replace the anemometer cup assembly. If only the wind speed system is being performance-tested, restore the meteorological tower and secure it in the upright position by reversing the procedure described in Section 7.1.1, Step 1 (as applicable).

c) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that valid data is again being collected. Record the time (*Local Standard Time*) that the data channel(s) were returned on-line in the space provided on the Audit Form(s) and in the site logbook entry for that day.

d) Enter the time that the wind speed system was restored to normal operation on Form 10-2, in the site logbook, providing a precise time reference for data review personnel.

e) Ensure all documentation is complete and that all measurement system components are functioning normally.

10.2.1.7 Documentation (presented at end of Section 10)

- Performance Test Data for Horizontal Wind Speed Measurement Systems (Form 10-2).
- Meteorological Audit Standards and Equipment (Form 10-10).
- Non-Conformance/Corrective Action (NC/CA) Report documenting any test results which exceeded acceptability limits. Refer to Section 9.2 in this document for instructions regarding NC/CA reports.

10.2.2 Vertical Wind Speed System Performance Test

10.2.2.1 Purpose and Scope

The purpose of this procedure is to provide instruction for conducting authoritative tests designed to assess the accuracy and performance of the entire vertical wind speed monitoring system. This procedure also provides instructions for documenting and evaluating the test results.

Implementation of this procedure by an independent auditor, using equipment other than that normally utilized for routine network operation, constitutes an independent performance audit on the wind speed measurement system. This procedure is also used for assessing the measurement system accuracy when the operational status of the vertical wind speed sensor is suspect, or when sensor failure requires repair or replacement.

10.2.1.2 Frequency

Performance audits should be conducted at least semiannually following station startup. System performance tests should be performed in conjunction with station startup and also when a problem with the sensor which might affect data accuracy is suspected or confirmed. Refer to Section 7, "Preventive and Corrective Maintenance", in Part 3 of this document for further guidance on conducting system performance tests in conjunction with corrective maintenance on the sensor.

10.2.1.3 References

- Refer to Section 10.1.3 for a listing of references.

10.2.1.4 Test Equipment

- NIST-traceable frequency counter with 0.01 sec/100 Hz resolution and an accuracy of ±1 count □ time base uncertainty.

- Certified variable speed or synchronous anemometer drive motor(s) with an accuracy of ±1 RPM at (minimum) 300 and 600 RPM.

- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).

10.2.1.6 Procedure for Vertical Wind Speed System Performance Test

m) Enter start of test (date, time, and initials) on Form 10-3 and in the site logbook. Indicate whether the performance test for vertical wind speed systems is a performance audit or unscheduled system calibration test by checking the appropriate space at the top of Form 10-3. If the performance test is not an audit, explain the reason for the test in the "Comments" section at the bottom of Form 10-2.

n) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that either an audit or system performance test, as applicable, is being performed and that the data must not be entered into the monitored data base. Record the time (*Local Standard Time*) that the data channels were marked off-line in the space provided on the Audit Form(s) and in the site logbook entry for that day.

o) Access the wind speed sensor. Refer to the instructions provided in Section 7.1.1, Step 2 of this document for accessing the wind speed sensor on the meteorological tower.

p) Remove the anemometer cup assembly according to the manufacturer's instructions. The complete absence of rotation of the sensor hub and shaft represents dead calm conditions. Record the corresponding DAS response (in engineering units) in the spaces provided in the "As Found" section on Form 10-3 under "System Test Results". Subtract the target response (i.e., 0.3 mph) from the DAS engineering unit response to compute the error (in mph). Record the error in the space provided in the "As Found" section on Form 10-2 under "System Test Results".

q) Attach the certified anemometer drive motor to the anemometer cup shaft to rotate the sensor’s shaft at a minimum of two (and preferably three) simulated wind speeds (e.g., 4.2, 8.4, and/or 12.6 mph) in the clockwise direction. Refer to the manufacturer’s published transfer function for the wind speed sensor to determine the required rotational rates for simulated wind speeds. (For the Climatronics

102236 vertical component wind speed sensor 300 RPM = 4.2 mph; 600 RPM = 8.4 mph and 900 RPM = 12.6 mph).

The motor should be run until a stable response for each simulated wind speed is obtained. Record the corresponding DAS response (in engineering units) for each simulated wind speed in the spaces provided in the "As Found" section on Form 10-3 under "System Test Results".

Repeat Step q. rotating the sensor’s shaft in the counter-clockwise direction.

r) Subtract the expected (target) value (in m/s) from the DAS response to compute the error for each test condition. Record each error (rounding to the nearest tenth of a m/s) in the spaces provided in the "As Found" section of Form 10-3, under "System Test Results".

s) Perform a sensor bearing torque check as described in Section 7.1.1, Step 5 in this document. Record the torque check result in the "As Found" space provided on Form 10-2. Provide documentation of the bearing replacement date, as well as the next replacement due date, in the "As Found" spaces provided on Form 10-3.

t) Evaluate the sensor starting torque and bearing maintenance status in accordance with the criteria and maintenance requirements described in Section 7.1.1, Step 6. If preventive or corrective maintenance is required, refer to Step 7 in Section 7.1.1, and follow the procedure for sensor maintenance described in that step. If maintenance consists of sensor replacement, record the replacement sensor serial number (S/N) in the designated spaces provided in the "As Left" sections of Form 10-3. If the original sensor is returned to service following maintenance, record that sensor S/N in the appropriate spaces in the "As Left" sections on Form 10-3.

u) Evaluate the "As Found" System Test Results obtained in conjunction with Steps b and c above with the acceptability limit for measurement system accuracy below:

Acceptability Limit For Wind Speed System Performance Test Results: Wind speed error should not exceed ±0.2 m/s (±0.44 mph).

v) If each of the System Test errors obtained in Step f) above is within the acceptability limits for wind speed measurement accuracy, and no maintenance or adjustment was required or performed on the sensor following the completion of "As Found" Performance Tests, then proceed to 10.2.1.6 ("System Restoration") below.

w) If any of the System Test errors exceeds the acceptability limits for accuracy stated above, *or* if any maintenance was performed which might affect the performance of the sensor (including replacement of the sensor or sensor bearings), then repeat the System Performance Tests described in Steps d) through

h) above and record these test results in the "*As Left*" section on Form 10-3 under "System Test Results".

x) Evaluate all "*As Left*" System Test results by comparing the "As Left" errors with the acceptability limits for accuracy above. If the "As Left" System Test results are within the acceptability limits for wind speed accuracy, then proceed to 10.2.1.6 ("System Restoration") below. If any error exceeds the acceptability criteria for accuracy, investigate to find the cause of the problem and establish a plan of action to promptly correct the condition. Satisfactory System Test results must be obtained before the problem can be considered successfully resolved and valid wind speed data collection resumed.

10.2.1.6 System Restoration

f) Remove all test equipment utilized in the performance of this procedure.

g) Replace the anemometer cup assembly. If only the wind speed system is being performance-tested, restore the meteorological tower and secure it in the upright position by reversing the procedure described in Section 7.1.1, Step 1 (as applicable).

h) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that valid data is again being collected. Record the time (*Local Standard Time*) that the data channel(s) were returned on-line in the space provided on the Audit Form(s) and in the site logbook entry for that day.

i) Enter the time that the wind speed system was restored to normal operation on Form 10-3, in the site logbook, providing a precise time reference for data review personnel.

j) Ensure all documentation is complete and that all measurement system components are functioning normally.

10.2.1.7 Documentation (presented at end of Section 10)

- Performance Test Data for Vertical Wind Speed Measurement Systems (Form 10-3).
- Meteorological Audit Standards and Equipment (Form 10-10).
- Non-Conformance/Corrective Action (NC/CA) Report documenting any test results which exceeded acceptability limits. Refer to Section 9.2 in this document for instructions regarding NC/CA reports.

10.2.2 Wind Direction System Performance Test

10.2.2.1 Purpose and Scope

The purpose of this procedure is to provide instruction for conducting authoritative tests designed to assess the performance and accuracy of the entire wind direction monitoring system. This procedure also provides instructions for documenting and evaluating the test results.

Implementation of this procedure by an independent auditor, using equipment other than that normally utilized for routine network operation, constitutes an independent performance audit on the wind direction measurement system. This procedure is also used for assessing the measurement system accuracy when the operational status of the wind direction sensor is suspect, or when failure requires repair or replacement of the sensor.

10.2.2.2 Frequency

Performance audits should be conducted at least semiannually following station startup. System performance tests should be performed in conjunction with station startup and also when a problem with the sensor which might affect data accuracy is suspected or confirmed. Refer to Section 7 (Preventive and Corrective Maintenance) in this document for further guidance on conducting system performance tests in conjunction with corrective maintenance on the sensor.

10.2.2.3 References

Refer to Section 10.1.3 above for a list of references.

10.2.2.4 Test Equipment

- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).
- Climatronics Azimuth Linearity Test Fixture (P/N 101754).
- NIST-traceable torque measurement device with a minimum accuracy of ≤ 5% of reading over a range of 3 to 24 gm-cm (e.g., Waters Torque Watch Model 366-1M).
- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).
- Climatronics keyed-mount sighting scope (P/N 101126) and authoritative benchmark or landmark of known azimuth heading relative to the meteorological tower; **or**
- Surveyor’s transit; **or**
- High-quality compass (e.g., Brunton “Pocket Transit” or equivalent).

10.2.2.5 Procedure for Wind Direction System Performance Test

a) Enter start of audit (date, time, and initials) on Form 10-4 and in the site logbook. Indicate whether the wind direction performance test is an audit or unscheduled system calibration test by checking the appropriate space at the top of Form 10-4. If the performance test is not an audit, explain the reason for the test in the "Comments" section at the bottom of Form 10-4.

b) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that a performance test (or audit) is being performed and that the data must not be entered into the monitored data base. Record the time (*Local* *Standard* *Time*) that the data channels were marked off-line in the space provided on the Audit Form(s) and in the site logbook entry for that day, providing a precise time reference for data review personnel.

10.2.2.5.1 Wind Direction Crossarm Alignment Check

a) Check the accuracy of the azimuth alignment of the crossarm (if aligned on the true north-south axis) or align the sensor's vane itself to true north (or south) using either the solar angle or true solar noon method to determine true north, or using a Global Positioning System device, surveyor's transit or compass to determine true north (the latter two methods require correcting for magnetic declination at the monitoring site location). If there is an existing landmark or benchmark indicating a known azimuth heading (e.g., true north or south), then the wind direction alignment may be checked with the Climatronics keyed-mount sighting scope or surveyors transit. Refer to Section 2.3.2.1 in this document for detailed instructions on assessing the Climatronics F-460 crossarm alignment with respect to true north.

b) Record the accuracy of crossarm alignment relative to true north (in degrees, resolving to the nearest tenth of a degree) in the space provided on Form 10-4. Observe the convention for polarity of this assessment: if the crossarm orientation deviates west of true north, the polarity of the error (in degrees) is negative. If the crossarm alignment deviates to the east of true north, the error is a positive value.

c) **Acceptability Limit:** The crossarm orientation should be within $\pm 3^o$ of true north (it should be noted that the *total* wind direction measurement system error is assessed on the basis of the algebraic sum of both the crossarm orientation error *and* sensor azimuth response error (see Section 10.2.2.5.2 below). The algebraic sum of these errors *may* result in an acceptable Total WD measurement system error).

If the crossarm alignment error is > ±3°, the orientation assessment should be carefully reviewed and checked for correctness. If the magnitude of alignment error is confirmed by this re-check, then the crossarm should be re-aligned to true north by following the procedure outlined in Section 2.3.2.1 of this document. Record the fact that the crossarm was re-aligned, and record the "As Left" measured deviation of the adjusted crossarm orientation relative to true north in the "Comments" section of Form 10-4 and in the site logbook. Complete a NC/CA Report to document this event. Refer to Section 9.3 in this document for instructions on NC/CA Reports.

10.2.2.5.2 Wind Direction Sensor Azimuth Response Check

a) Follow the directions provided in Section 7.1.1, Step 2, for accessing the sensor on the tower. Remove the vane from the wind direction sensor in accordance with the manufacturer's instructions. Ensure that the top hub of the sensor (upon which the vane hub mounts) is not loosened by mistake when removing the vane. Next, remove the wind direction sensor from its keyed crossarm mounting socket according to the manufacturer's instructions. Install the sensor into the keyed mounting socket of the Climatronics azimuth linearity test fixture. Plug the Amphenol signal connector of the test fixture into the crossarm socket normally occupied by the sensor.

b) Install the precision azimuth (“degree”) wheel in place of the vane, being sure that it mates correctly with the keyed sensor vane mounting hub. The precision azimuth degree wheel is now a surrogate for the vane, and will be fixed at a sequence of known azimuth headings. The keyed sensor mounting socket of the linearity test fixture ensures correct positioning of the sensor body relative to the pointer, which engages the notched azimuth degree wheel. The pointer tip indicates the known azimuth degree heading for the sensor.

c) Sequentially rotate the degree wheel to each of the known azimuth headings (“test points”) described below. For each azimuth test point, the tester should wait until a stable wind direction is observed from the DAS. The corresponding stable DAS responses (in engineering units) should be recorded in the designated "As Found" spaces in the "System Test Results" section of Form 10-4.

IMPORTANT NOTE: Definitive acceptability limits for total wind direction monitoring system accuracy are set forth in Step i below. Steps d through g below provide suggested tolerance values (referenced in parentheses) for DAS responses for each azimuth test point. These suggested tolerances are typical of a well-maintained system's response to these test points. As such, they provide a useful guideline for sensor adjustment following any maintenance.

d) Set the degree wheel at the 90° position and record the resultant stable DAS response (in engineering units) in the designated spaces provided in the “As Found” “System Test Results” section of Form 10-4. The DAS target response is 90^o ($\pm 2^o$).

e) Slowly rotate the degree wheel clockwise to the 180° position and record the stable DAS actual response as described in Step d) above. Target response is 180^o ($\pm 2^o$).

f) Slowly rotate the degree wheel clockwise to the 270° position and record the stable DAS response as described in Step d) above. Target response is 270^o ($\pm 2^o$).

g) Slowly rotate the degree wheel clockwise and set it in the 0° position. Record the stable DAS actual response as described in Step d) above. Target response is 0^o or 360^o ($\pm 2^o$).

h) For each azimuth (degree wheel) test point obtained in Steps d through g above, evaluate the total system error by using Equation 3:

$$\text{WD Total Error} = (WD_{DAS} - WD_{known}) - (\text{Crossarm Bias}) \qquad \textbf{\textit{Equation 3}}$$

Where:

WD Total Error = the total error of the wind direction measurement system at each azimuth test point, in degrees.

WD_{known} = the known, or true, value of each azimuth test point as indicated by the azimuth degree wheel setting, in degrees.

WD_{DAS} = the observed response of the data acquisition system to each azimuth test point, in degrees.

Crossarm Bias = the deviation of the crossarm orientation with respect to the true north-south axis, in degrees. (Note: If the crossarm is aligned west of true north, the crossarm bias value is negative; if it is aligned to the east of true north, the crossarm bias value is positive. *Retain these polarities when resolving Equation 3*).

Record the total wind direction system measurement error for each azimuth test point in the designated spaces provided under the “As Found” columns in the “System Test Results” section of Form 10-4.

i) **Acceptability Limit:** The WD Total Error should not exceed $\pm 5^o$. If each of the "As Found" System Test errors obtained in conjunction with Steps a-h above satisfies the acceptability criteria for wind direction accuracy, and no maintenance or adjustment was required or performed on the sensor following completion of all "As Found" Performance Tests, then proceed to section 10.2.2.7 ("System Restoration") below.

If the any of the WD Total Error values exceeds $\pm 5^o$, investigate to determine which of the monitoring system components needs adjustment or corrective maintenance. Compare the "As Found" System Performance Test responses recorded on Form 10-4 with the suggested tolerance values for crossarm alignment error ($\pm 3^o$) and sensor azimuth response ($\pm 2^o$). It should be evident which system component requires adjustment. Refer to Section 7 in this document for instructions and procedures regarding performing corrective maintenance on the various instruments.

10.2.2.5.3 Wind Direction Sensor Starting Torque Check

a) Remove the degree wheel from the sensor's vane-mounting hub and check the "As Found" sensor bearing torque using a certified torque measurement standard. This procedure assumes the torque measurement device used is the Waters Model 366-1M torque watch. Attach the chuck for the torque watch to the shaft protruding from the top hub of the sensor. Gently set the toque watch pin into the square depression in the top of the chuck. Slowly rotate the torque watch a complete rotation (360^o) in both the clockwise *and* counterclockwise directions and observe the maximum starting torque indication obtained for each direction of rotation. Record the highest force measurement observed in each direction of rotation in gm-cm (resolving to the nearest 0.1 gm-cm) in the "As Found" torque check spaces provided on Form 10-4.

   Acceptability Limit: The maximum acceptable starting torque for the Climatronics F-460 wind direction sensor is $\leq$ 6.0 gm-cm in both directions of rotation.

b) The bearing in the Climatronics F-460 wind direction sensor is typically replaced after approximately six months of continuous use. The internal friction in this bearing is a primary determinate of the sensor's starting torque, however, the friction of the wiper in the sensor's potentiometer and other sensor components also affect the overall starting torque. Refer to Section 7.2.1, Steps 4 and 5, for procedures for performing bearing replacement and other maintenance on the wind direction sensor.

10.2.2.6 "As Left" Wind Direction System Performance Tests

If any preventive or corrective maintenance was performed that could affect the performance of the sensor, or if maintenance consisted of replacing the sensor, then complete "As Left" System Performance Tests must be performed to assess and document the system performance following these activities.

a) If maintenance in the field is accomplished via sensor replacement, record the replacement sensor serial number (S/N) in the "As Left Sensor S/N" space provided in the "System Test Results" section of Form 10-4. If the original sensor is reinstalled following field maintenance, record that sensor's S/N in the "As Left Sensor S/N" space.

b) Repeat Step a in Section 10.2.2.5.3 ("Wind Direction Sensor Starting Torque Check") above. Record the "As Left" sensor torque in the "As Left" bearing torque check spaces provided on Form 10-4. Also record the date when the "As Left" sensor bearing was replaced and the "Due" date for future replacement in accordance with the preventive maintenance schedule provided in Section 7.2.

c) Repeat Steps b-i in Section 10.2.2.5.2 (“Wind Direction Sensor Azimuth Response Check”) above and record these test results in the "As Left" section on Form 10-4 under "System Test Results".

d) If all "As Left" test results satisfy the wind direction accuracy and acceptability criteria, then proceed to Section 10.2.2.7 ("System Restoration") below. If any of the "As Left" system test errors exceeds the acceptability criteria, investigate to find the cause of the problem and establish a plan of action to promptly correct the condition. Satisfactory System Performance Test results must be obtained before the problem can be considered successfully resolved and valid wind direction data collection resumed.

10.2.2.7 System Restoration

a) Remove all test equipment utilized in the performance of this procedure.

b) Replace the sensor on the crossarm mounting socket and the wind vane on the sensor, being sure that the vane is correctly mated with the keyed flat section of the sensor vane-mounting hub.

c) Check the crossarm position for any visible evidence of change from its normal (or re-aligned) orientation to true north. (Note: the crossarm orientation is rigidly fixed; any disturbance would require considerable force applied to the structure). If the crossarm orientation is disturbed, refer to the procedures set forth in Step c in Section 10.2.2.5 above and re-verify the crossarm orientation.

d) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that valid data is again being collected. For stations using the Campbell Scientific CR-1000 data logger, the appropriate action is to place the toggle switch in the “ON” position and the system is now ready to resume collection of valid, representative data.

e) Record the time (*Local Standard Time*) that the data channel(s) were returned on-line in the space provided on Form 10-3 and in the site logbook entry for that day.

f) Ensure that all information has been correctly entered on Form 10-4 and record a summary of the Performance Test results in the chronological site logbook. Ensure all documentation is complete.

10.2.2.8 Documentation (all forms are presented at the end of Section 10)

- Performance Test Data for Wind Direction Measurement Systems (Form 10-4).
- Meteorological Audit Standards and Equipment Summary Sheets (Form 10-10).

- Non-Conformance/Corrective Action (NC/CA) Report documenting any exceedance of acceptability limits for wind direction system performance tests. Refer to Section 9.2 in this document for instructions regarding NC/CA reports.

10.2.3 Ambient Temperature and Temperature Difference ("Δ-T") System Performance Tests

10.2.3.1 Purpose and Scope

The purpose of this procedure is to assess the performance and accuracy of the ambient air temperature and temperature difference (Δ-T) monitoring systems. This procedure also provides instructions for documenting and evaluating the test results with respect to established acceptability criteria.

Implementation of this procedure by an independent auditor, using equipment other than that normally utilized for routine network operation, constitutes an independent performance audit on the temperature measurement system. This procedure is also used for assessing the measurement system accuracy when the operational status of the temperature system is suspect, and to calibrate the system following repair or replacement of a component that could affect the accuracy of the measurement system.

10.2.3.2 Frequency

Performance audits should be conducted within 30 days following station startup and at least semi-annually thereafter. System performance tests should be performed in conjunction with station startup and also when a problem with the sensor which might affect data accuracy is suspected or confirmed. Refer to Section 7 (Preventive and Corrective Maintenance) in this document for further guidance on conducting system performance tests in conjunction with corrective maintenance on the system.

10.2.3.3 References

Refer to Section 10.1.3 above for a list of references.

10.2.3.4 Test Equipment

- NIST-traceable digital voltmeter with 0.001 volt resolution and an accuracy of ±0.05% of input ±1 digit.

- NIST-traceable reference thermometer(s) with a minimum accuracy of ±0.1°C of reading and covering a temperature range of 0^{o}C to 40^{o}C with 0.05^{o}C resolution.

- An additional NIST-traceable reference thermometer with a minimum accuracy of ±0.1°C of reading and covering a minimum temperature range of 15^{o}C to 30^{o}C with 0.05^{o}C resolution.

- Three insulated water containers, minimum 1-quart capacity, Thermos-type.

- Distilled water.
- Crushed ice.
- Submersible heating element.
- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).

10.2.3.5 Procedure for Ambient Temperature and Temperature Difference ("Δ-T") System Performance Tests

NOTE: The monitoring system incorporates measurement systems for both ambient air temperature (measured at 2m AGL) and Δ-T (measured at 10m AGL). This procedure presents instructions for conducting performance tests for *BOTH* the Ambient Temperature and Δ-T measurement systems concurrently.

a) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that an audit (or system performance test, as applicable) is being performed and that the data must not be entered into the monitored data base. For sites using the Campbell Scientific CR-1000 data logger, the appropriate action is to place the status toggle switch in the "OFF" position.

b) Record the start of test (date, time, and initials) on Form 10-5, Form 10-6 and in the site logbook for the parameters undergoing test. Indicate whether the test is a performance audit or calibration test in the site logbook and also by checking the appropriate space at the top of Forms 10-5 and 10-6. If the performance test is not an audit, explain the reason for the test in the "Comments" section at the bottom of Forms 10-5 and/or 10-6, as appropriate.

10.2.3.5 Temperature System and Temperature Difference ("Δ-T") Performance Test

a) Disconnect the 115 VAC power to the aspirator motors in the temperature and Δ-T radiation shield housings.

b) Refer to Section 7.1.1 (Step 2) of this document and implement the instructions to access the tower-mounted sensors.

c) Remove the Δ-T radiation shield housing from the tower (mounted at the 10m level), free the associated signal cable from any ties securing it to the tower and position the shield housing adjacent to the shield housing for the ambient temperature probe (located at the 2m level on the tower).

d) Follow the procedure in Section 2.3.3.2 of this document to remove the temperature probes from the front opening of their respective radiation shield housings. Keep the electrical connections intact from the probe leads to the barrier strip within each shield housing and all signal cabling leading from the shield housings to the DAS.

e) Sustain each of the test conditions described in Steps e) through q) below for at least 6-12 minutes. For operational ambient temperature and Δ-T measurements systems, complete performance test data must be obtained and recorded before performing any adjustments or maintenance on either measurement system. *Unadjusted* test data are recorded in the "*As Found*" columns and spaces provided in the "System Performance Test Results" sections of Forms 10-5 and 10-6.

f) Fill a thermos with crushed ice and just enough distilled water to form an ice slurry mixture. Using rubber bands to hold the temperature probe, Δ-T probe and reference thermometer closely together (ensure the probe tips and thermometer bulb are aligned next to each other). Place the probes and reference thermometer in the container of ice slurry, submerging to a depth equal to the immersion line on the reference thermometer (approximately 3 inches). Ensure that the probe tips and thermometer bulb are submerged at the same level.

g) While constantly agitating the ice slurry mixture, monitor the instantaneous DAS readings (in engineering units) for both the ambient and Δ-T temperature channels. After 6-12 minutes, record the following observed, stable test values in the "System Performance Test Results" sections of Forms 10-5 and 10-6 as indicated:

- DAS ambient temperature reading (to the nearest tenth of a °C) on Form 10-5.
- The reference thermometer reading (to the nearest 0.05°C) on Form 10-5.
- The reference thermometer reading (to the nearest 0.05°C) in the spaces marked "Ambient Reference Temperature" and "Δ-T Reference Temperature" on Form 10-6. (Note: Because both the Ambient and Δ-T probes are in the same temperature bath, the reference temperature for each probe is the same).
- DAS Δ-T reading (to the nearest hundredth of a °C) in the space marked "Δ-T DAS" on Form 10-6.

h) Place the probes and reference thermometer in an insulated container of water that has been allowed to equilibrate at "ambient" temperature (approximately 15^{o}C to 25°C) and obtain and record the stable system responses and corresponding reference thermometer indication as described in Step g) above.

i) Place probes and reference thermometer in an insulated container of hot water that has been heated and allowed to equilibrate to a temperature within the range of approximately 35^{o} ~ 45^{o} C. After ~ 6 to 12 minutes, obtain and record the stable system responses and corresponding reference thermometer indication as described in Step g) above.

<u>NOTE</u>: Steps j) through q) below test the accuracy of the Δ-T measurement system response in conditions that produce <u>non-zero</u> Δ-T target values. All test data for these steps are recorded on Form 10-6 only.

j) Prepare two stable temperature baths in separate thermoses. One bath should be at "ambient" or "room" temperature (approximately 15^{o}C to 25^{o}C). The second bath should be approximately 4^{o}C to 4.5 ^{o}C warmer than the "ambient" bath. Agitate the baths thoroughly to ensure the water temperature is homogeneous within each thermos. Verify the specified temperature difference between the two baths has been maintained by using two reference thermometers, one immersed in each bath.

k) Using rubber bands to hold the *ambient* temperature probe and one reference thermometer closely together (ensure the probe tips and thermometer bulb are aligned next to each other), insert the *ambient* temperature probe and reference thermometer through the hole in the insulating thermos cover used in Step j) above and *place the cover on the warmer thermos bath*. Ensure the probe tip and thermometer bulb are aligned next to each other and submerged in the water bath to a depth of approximately 3 inches.

l) Using the same technique as described in Step k) above, place the *Δ-T* probe and a second reference thermometer in the "ambient/room"-temperature bath.

m) Allow approximately six minutes for the probes and reference thermometers to stabilize at the bath temperature conditions. When stable values are evident, record the following test readings in the "System Test Results" section of Form 10-6:

- The stable DAS response for Δ-T (in engineering units) in the space marked "Δ-T DAS".

- The reference thermometer temperature reading for the *ambient* probe bath (resolving to the nearest 0.05 ^{o}C) in the space labeled "Ambient Reference Temperature".

- The stable reference thermometer temperature reading for the *Δ-T* probe bath (resolving to the nearest 0.05 ^{o}C) in the space labeled "Δ-T Reference Temperature".

- Subtract the "Ambient Reference Temperature" value from the "Δ-T Reference Temperature" value to obtain the "Δ-T Target" value (this value should be approximately -4.0^{o}C to -4.5 ^{o}C). Round this value to the nearest hundredth of a ^{o}C and record it in the space labeled "Δ-T Target".

n) Prepare two stable temperature baths in separate thermoses as described in Step j) above. This time, however, the warmer bath should be heated approximately 9^{o}C to 9.5 ^{o}C warmer than the “ambient” bath. Agitate the baths thoroughly to ensure the water temperature is homogeneous within each thermos. Verify the specified temperature difference between the two baths is achieved by using two reference thermometers, one immersed in each bath.

o) Using the same technique as described in Step k) above, place the *ambient* temperature probe and a reference thermometer in the “ambient/room”-temperature bath.

p) Using the same technique as described in Step k) above, place the *Δ-T* probe and a second reference thermometer in the warmer-temperature bath.

q) Repeat Step m) above to obtain and record the stable “Δ-T DAS” value, “Ambient Reference Temperature” value, the “Δ-T Reference Temperature” value, and the “Δ-T Target” value (this value should be approximately +9^{o}C to +9.5 ^{o}C).

r) Calculate Ambient Temperature System Errors: For each ambient temperature test point recorded on Form 10-4, subtract the reference thermometer indication (in °C) from the corresponding DAS Ambient Temperature indication (in °C). Record each resulting difference value in the “System Error” column on Form 10-5.

s) Calculate Δ-T System Errors: For each test point on Form 10-6, subtract the “Target Δ-T Temperature” value (in ^{o}C) from the corresponding observed “Δ-T DAS” value (in ^{o}C). Record each difference value (in ^{o}C, rounding to the nearest hundredth of a degree) in the “Δ-T Error” column in the System Performance Test Data section of Form 10-6.

t) **Acceptability Limit For Ambient Temperature Test Results:** For each ambient temperature test point recorded on Form 10-5, the “System Error” should not exceed ±0.5^{o}C. Evaluate the test results obtained in Step r) above against this accuracy acceptance criterion.

Acceptability Limit For Δ-T Test Results: For each Δ-T test point recorded on Form 10-6, the “Δ-T Error” should not exceed ±0.1^{o}C. Evaluate the test results obtained in Step s) above against this accuracy acceptance criterion.

If all test results are within the stated acceptability limits, proceed to Section 10.2.3.6 below.

u) If any of the System Test errors exceed the acceptability criterion for accuracy stated in Step t) above, investigate to find the cause of the problem and establish a plan of action to correct the condition. Satisfactory system performance test results must be obtained before the problem can be considered resolved and valid ambient air temperature data collection resumed.

v) When corrective actions are complete, repeat the temperature bath tests described in Steps e) through t) above. Record these test results in the "As Left" section of the "System Test Results" on Forms 10-5 and/or 10-6 as appropriate. Describe the assignable cause of the problem and corrective actions taken to restore the system accuracy to an acceptable level of performance in the "Comments" section of Forms 10-5 and/or 10-6 as appropriate.

10.2.3.6 System Restoration

a) Re-install the temperature and Δ-T probes in their respective inner shield assemblies and re-install each assembly into the radiation shield designated for each probe. (The ambient temperature probe and radiation shield is mounted at 2m AGL on the tower; the Δ-T probe and radiation shield is mounted at 10m AGL on the tower.) If either radiation shield was removed from the tower for the System Performance Test, re-install it on the tower.

b) Restore power to the aspirator motors.

c) Verify both the ambient temperature and Δ-T systems are operating normally or note any exceptions in the "Comments" section of Form 10-5 and/or Form 10-6 as appropriate. Provide the necessary status information to the DAS to indicate that the ambient and Δ-T temperature data are to be included in the data base. For stations using the Campbell Scientific CR-1000 data logger, the appropriate action is to place the toggle switch in the "ON" position and the system is now ready to resume collection of valid, representative data.

d) Record the time (*Local <u>Standard</u> Time*) that the data channel(s) was returned on-line in the space provided on Form 10-4 and in the site logbook entry for that day.

e) Ensure all documentation is complete.

f) Remove all test equipment utilized in the performance of this procedure.

10.2.3.7 <u>Documentation</u> (examples of all forms are presented at the end of Section 10)

- Performance Test Data for Ambient Temperature Measurement Systems (Form 10-5).
- Performance Test Data for Temperature Difference Measurement Systems (Form 10-6).
- Meteorological Audit Standards and Equipment sheet (Form 10-10).
- Non-Conformance/Corrective Action (NC/CA) Report documenting any exceedance of acceptability limits for ambient temperature system performance test. Refer to Section 9.2 in this document for instructions regarding NC/CA reports.

10.2.4 <u>Solar Radiation System Performance Tests</u>

10.2.4.1 Purpose and Scope

The purpose of this procedure is to provide instruction for conducting authoritative tests designed to assess the performance and accuracy of the solar radiation measurement system. This procedure also provides instructions for documenting and evaluating the test results.

Implementation of this procedure by an independent auditor, using equipment other than that normally utilized for routine network operation, constitutes an independent performance audit of the dew point measurement system. This procedure is also used for assessing the measurement system accuracy when the operational status of the solar radiation sensor is suspect, or when failure requires repair or replacement of the sensor.

The only practical method for obtaining a meaningful assessment of the accuracy of a solar radiation measurement system in the field involves utilization of a collocated transfer standard (CTS). The CTS consists of a certified duplicate of the on-site measurement system. It is temporarily installed and operated side-by-side with the on-site system for a time interval commensurate with obtaining sufficient data to support a statistically valid comparison of the data produced by the two measurement systems. For this monitoring program, a minimum of 720 consecutive pairs of 1-minute data values (i.e., twelve consecutive hours of 1-minute data, preferably including substantial periods of strong sunlight) will be obtained to provide a valid accuracy audit assessment.

10.2.4.2 Frequency

Performance audits should be conducted at least semiannually following station startup. System performance tests should be performed in conjunction with station startup and also when a problem with the sensor which might affect data accuracy is suspected or confirmed. Refer to Section 7 (Preventive and Corrective Maintenance) in this document for further guidance on conducting system performance tests in conjunction with corrective maintenance on the system.

10.2.4.3 References

Refer to Section 10.1.3 above for a list of references.

10.2.4.4 Test Equipment

- A certified (within the previous 12 months) Eppley Model 8-48 (“Black & White”) pyranometer with mounting plate, 50-foot signal cable.

- Standard assortment of electronics hand tools (e.g., needle nose pliers, hex key set, screwdrivers, cutting pliers, etc.).

- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).

10.2.4.5 Procedure for Solar Radiation System Performance Tests

The auditor (or site operator, as appropriate) should plan to install the CTS solar radiation sensor and initialize an analog input channel in the site data logger so that the comparison test data set will include at least 12 consecutive hours of daylight measurements (preferably including substantial periods of strong sunlight). This may require setting up the CTS measurement system one day in advance of the test. If this is the case, the CTS system may be left operating overnight so that data collection will already be in progress at sunrise.

a) Install the CTS sensor on a rigid support base adjacent to the site sensor (reference Section 2.3.6 of this document for instructions on installing the sensor). Exercise care while installing the audit radiation sensor to ensure that the current orientation and condition of the on-site radiation sensor is not altered. If CTS installation activity blocks the site sensor's exposure to sunlight, provide the proper status information to the site digital data acquisition system (DAS) indicating that the data must temporarily be excluded from the monitored data base.
b) Route the stripped wire end of the CTS sensor signal cable through an available port located in the bottom panel of the NEMA 4X enclosure that houses the data acquisition system (DAS) on the met tower. Make the necessary signal wiring connections to the designated spare signal input terminals on the Signal Line Surge Protector (SLP) module (refer to the Climatronics Corp. System Engineering Manual to identify the correct wiring configuration).

c) Route the remaining length of the 50' CTS sensor signal cable to the CTS sensor and attach the twist-lock bayonet connector to the CTS sensor.

d) Initialize an unused data logger analog input channel as the designated "CTS Sol Rad" data channel. The initialization of this data channel will be identical to the site-designated solar radiation data channel, except the scaling factors entered for the "CTS Sol Rad" data channel will be the transfer function determined by Eppley from the most recent certification of the CTS sensor. Ensure that the data logger initialization instructions for both of the solar radiation data channels includes storage of 1-minute data values (refer to the Campbell Scientific CR-1000 data logger Engineering Manual for instructions on initialization of analog input channels and associated data averaging functions). The solar radiation CTS should now be fully operational.

e) Fill out the header information and monitoring system component identification information called out in the designated spaces on Form 10-7 (note that there are separate sections on Form 10-7 for identifying the "Site" monitoring system components and the "Audit" or CTS system components). Record the start of test (date, time, and initials) on Form 10-7 and in the site logbook. Indicate whether the test is a performance audit or unscheduled system calibration check by annotating the fact in the site logbook and by checking the appropriate space at the top of Form 10-6. If the performance test is not an audit, explain the reason for the test in the "Comments" section at the bottom of Form 10-7.

f) Confirm that both the CTS and on-site solar radiation measurement systems are operating properly and collecting ambient measurement data. Note the current time and date displayed on the data logger and record this as the “Test Begin” time in the designated space provided on Form 10-7.

g) Allow the on-site data logger to collect at least 12 consecutive hours of data during daylight hours from both the on-site and the CTS solar radiation measurement systems. Data collection can progress unattended however, a cursory review of the hourly data produced by both measurement systems during the course of the performance test is recommended to confirm proper operation.

h) After the performance test period requirement is met, download the associated 1-minute and hourly-averaged data from the on-site data logger. This can be done using a local laptop PC or via the remote data polling PC. Section 5.3 in this document provides instructions for establishing local communications with the data logger using a laptop PC.

i) Record the “End” time and date of the performance test data collection interval in the designated space on Form 10-7.

10.2.4.6 System Restoration

a.) Following downloading of the performance test data, remove the CTS measurement system components by performing Steps a) through d) in Section 10.2.4.5 above in reverse order.

b.) Ensure all documentation of the performance test has been properly recorded in the site logbook and on Form 10-7. Verify the data status switch is in the ON position and the monitoring system is functioning normally.

10.2.4.7 Analysis of the Solar Radiation System Performance Test Data

The hourly-averaged solar radiation time-series data produced by each measurement system during the performance test are exported to a standard PC-based spreadsheet (e.g., Microsoft Excel tm) for analysis as follows:

a.) Paired data values (CTS system data and on-site system data) are correlated with respect to time and date. The date and time for each pair of data values should be included in the spreadsheet for reference purposes.

b.) Exclude from all subsequent analyses of the data any data pair for which either or both hourly-averaged value is ≤ 10% of the full scale measurement range (i.e., ≤ 140W/m^2).

c.) Using the non-excluded data values, calculate the mean (average) value for each data set.

d.) For each remaining pair of data values (including the mean value for each data set) subtract the Audit CTS value from the corresponding Site measurement system data value to calculate the difference.

e.) For each remaining pair of data values (including the mean value for each data set) calculate the percent difference (Δ%) using Equation 4:

$$\Delta\%_{SolarRad} = \left(\frac{Site\ Value - CTS\,Value}{CTS\,Value} \right) \times 100 \ \square$$

Equation 4

f.) Evaluate the comparability of the performance test data set by calculating the standard deviation of the difference values determined in Step d above using Equations 5 and 6:

$$C = \pm \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left(X_{ai} - X_{bi} \right)^2} \qquad \textbf{\textit{Equation 5}}$$

W*here*:

C = Operational Comparability factor for the Collocated Transfer Standard;
X_{ai} = the i^{th} data value produced by the site measurement system;
X_{bi} = the i^{th} data value produced by the CTS measurement system; and
n = the number of paired data values in the comparison.

And:

$$s = \pm \sqrt{C^2 - d^2} \qquad \textbf{\textit{Equation 6}}$$

Where:

s = the estimated standard deviation of the differences of each data pair in the data comparison set; and
d = the average difference between the site measurement data and the CTS measurement data, as determined in Step e) above.

g.) Evaluate the standard deviation value *s* with respect to the average percent difference value obtained in Step e) above. If *s* is significantly less than the average percent difference value, than the performance test results can be considered representative for comparability. If, however, *s* is nearly the same magnitude as the average percent difference result (or if *s* is equal to or greater than the average percent difference), there is reason to suspect that the CTS test data were significantly influenced by a variable biasing condition or factor(s) extant during the comparison test, or that the performance of the CTS system itself was deficient.

If *s* is not significantly less than the average percent difference result, the CTS test result may not be represent a valid assessment of the site measurement system accuracy. If this is the case, the siting, circumstances and conditions in which the CTS test data were obtained should be carefully reviewed for possible biasing factors. A review of the individual, time-series data pairs and their relative values may reveal a pattern that can provide clues to possible contributing factors or circumstances.

If a substantial percentage of the comparison test data values are ≤ 10% of the full scale measurement range, relatively small differences between the CTS and site data values can translate into large percent difference values, and this may unduly skew the comparison analysis results (whenever possible, comparison tests should be conducted under predominately sunny conditions that will produce substantially upscale measurement data).

If no cause of the bias or excessive variability in the test results can be determined from this qualitative review, confirmation of the performance and accuracy of the CTS itself may be indicated. The Project Manager should be immediately informed of anomalous or unacceptable performance test results, and an action plan should be developed to resolve the issue. The status of the solar radiation data may be considered suspect pending results of the investigation and a definitive finding with respect to the CTS performance and status of the test data. A performance test of the site measurement system should be repeated as soon as practicable using either an alternative CTS or the original CTS (if confidence in this standard's performance and accuracy is high). The repeat performance test should be subject to careful observation and consideration of possible factors that may introduce an external variable bias factor in the test data.

10.2.4.8 Documentation (examples of all forms are presented at the end of Section 10)

- Performance Test Data for Solar Radiation Measurement Systems (Form 10-7).
- Meteorological Audit Standards and Equipment (Form 10-10).
- Non-Conformance/Corrective Action (NC/CA) Report documenting any test results which exceeded acceptability limits (see Section 9.2 in this document for instructions regarding NC/CA Reports).

10.2.5 Precipitation System Performance Tests

10.2.5.1 Purpose and Scope

The purpose of this procedure is to provide instruction for conducting authoritative tests designed to assess the performance and accuracy of the precipitation monitoring system. This procedure also provides instructions for documenting and evaluating the test results.

Implementation of this procedure by an independent auditor, using equipment other than that normally utilized for routine network operation, constitutes an independent performance audit of the precipitation measurement system. This procedure is also used for assessing the measurement system accuracy when the operational status of the precipitation sensor or measurement system is suspect, or when failure requires repair or replacement of the sensor.

10.2.5.2 Frequency

Performance audits should be conducted at least semiannually following station startup. System performance tests should be performed in conjunction with station startup and also when a problem with the sensor which might affect data accuracy is suspected or confirmed. Refer to Section 7 (Preventive and Corrective Maintenance) in this document for further guidance on conducting system performance tests in conjunction with corrective maintenance on the sensor.

10.2.5.3 References

Refer to Section 10.1.3 above for a list of references.

10.2.5.4 Test Equipment

- NIST-traceable digital voltmeter with 0.001 volt resolution and an accuracy of ±0.05% of input ±1 digit.
- Burette with minimum 25 ml capacity, stopcock, and minimum 0.1 ml graduated measurement markings. Burette should conform to Federal Specification No. NNN-B-0789a (e.g., Nalgene P/N 06198-20 or equivalent).
- Distilled Water.
- Carpenters' or torpedo spirit level.
- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).

10.2.5.5 Procedure for Precipitation System Performance Tests

The System Performance Test will consist of introducing a known volume of water that is subsequently converted to an equivalent "known" precipitation value using the manufacturer's transfer function for the gauge. The corresponding DAS precipitation measurement indication is then compared against the known (or reference) precipitation value. The percent difference between the DAS indication and the known value represents the total system error.

<u>NOTE</u>: The following steps must be performed within a single hourly block-averaging interval as referenced to the data logger clock. The auditor/operator must also ensure that during the hour in which the performance test is conducted no extraneous tips of the precipitation gauge's tipping buckets occur other than those prescribed by this procedure.

a) If the monitoring system incorporates a digital data acquisition system (DAS), provide the proper status information indicating that an audit (or system performance test, as applicable) is being performed and that the data must not be entered into the monitored data base. For stations using the Campbell Scientific CR-1000 data logger, the appropriate action is to place the toggle switch in the “OFF” position and the system is now unable to collect representative, valid data due to the maintenance or test activity to be performed.

b) Record the start of test (date, time, and initials) on Form 10-8 and in the site logbook, for the parameter undergoing test. Indicate whether the performance test for the precipitation measurement system is a performance audit or unscheduled system calibration check by annotating this fact in the site logbook and by checking the appropriate space at the top of Form 10-8. If the performance test is not an audit, explain the reason for the test in the "Comments" section at the bottom of Form 10-8.

c) Remove the gauge’s debris screen prior to the test.

d) Fill the graduated burette to the 25.0 ml line (Note: Reference the bottom of the meniscus when determining the water volume in the burette) and position the burette directly over the gauge’s opening. Slowly open the burette stopcock until water starts slowly dripping from the burette into the gauge (approximately 1 drop per second). Count each tip of the tipping buckets during this process.

e) Continue to introduce water into the gauge as described in Step d) (refilling the burette as necessary) until ten tips of the buckets are counted. Close the burette stopcock *immediately* after the tenth tip.

f) Record the total volume of water (to the nearest 0.1 ml) introduced into the gauge from the burette on line A-1 in the “System Performance Test” section of Form 10-7.

g) Record the total number of bucket tips on Line B-1 in the “System Performance Test” section of Form 10-6. Convert the number of tips to equivalent rainfall using the gauge manufacturer’s transfer function (for the Climatronics Model 100097 precipitation gauge, each tip equals 0.01” of precipitation. Assuming 10 tips were obtained in Step e) above, the equivalent precipitation is equal to 0.10”). Record this value on line B-2 in the “System Performance Test” section of Form 10-8.

h) When the hourly interval during which the performance test was conducted is complete, obtain and record the DAS precipitation indication for that hourly interval in the space provided on Line D) in the “System Performance Test” section of Form 10-8.

i) Refer to the total volume of water (in ml), which was recorded on Line A-1 in the "System Performance Test" section of Form 10-8. Using the manufacturer's transfer function for the precipitation gauge, convert the total volume of water introduced from the burette recorded in Step f) above to equivalent rainfall. (For the Climatronics model 100097 gauge, 8.24 ml of water = 1 tip = 0.01" precipitation. Therefore, to obtain the equivalent rainfall value for this gauge, divide the total volume of water introduced into the gauge by 8.24). Record the resulting equivalent precipitation value (to the nearest hundredth of an inch) on Line A-2 in the "System Performance Test" section of Form 10-8.

j) Calculate the total measurement system error in percent difference (Δ%) using Equation 7:

$$Percent\ Difference\ (\Delta\%) = \frac{D - A2}{A2} \times 100 \qquad \textbf{\textit{Equation 7}}$$

where,

A2 = "Known" total equivalent precipitation (introduced from burette), in inches

D = total precipitation for test hour indicated by the DAS, in inches

Record the percent difference (error) value on Line E in the "System Performance Test" section of Form 10-8.

k) **Acceptability Limit:** The acceptability limit established for total precipitation measurement system accuracy is ±10% compared to True. Evaluate the "As Found" System Performance Test results obtained in Step j) above with respect to this criterion.

l) If the System Performance Test error obtained in Step j) above is within the acceptability limit (i.e. ≤ ±10%) and no maintenance or adjustment was required or performed on the gauge following the completion of the "As Found" Performance Test, then proceed to 10.2.5.6 ("System Restoration") below.

If the System Performance Test error exceeds the acceptability criteria for accuracy stated above, or if any maintenance was performed which might affect the performance of the gauge (including replacement of the gauge, removal of substantial debris from the tipping buckets, adjustment to or lubrication of the tipping bucket pivots, or re-leveling the gauge), then repeat the System Performance Tests described in Steps a) through j) above and record the "As Left" test results on a separate Form 10-8.

Compare the "As Left" error with the acceptability criteria for accuracy above. If the test result satisfies the acceptability criteria for precipitation system accuracy, then *prominently label* the associated data recorded on a separate Form 10-8 "*As*

Left" and proceed to Section 10.2.5.6 ("System Restoration") below. If the System Performance Test error still exceeds the acceptability criteria, investigate to find the cause of the problem and establish a plan of action to promptly correct the condition. Satisfactory System Performance Test results must be obtained before the problem can be considered successfully resolved and valid precipitation data collection resumed.

10.2.5.6 System Restoration

a) Remove all test equipment utilized in the performance of this procedure.

b) Replace the precipitation gauge debris screen assembly.

c) Ensure all documentation is complete, the DAS mode switch is returned to the "ON" position, and that all measurement system components are functioning normally.

10.2.5.7 Documentation (examples of all forms are presented at end of Section 10)

- Performance Test Data for Precipitation Measurement Systems (Form 10-8).
- Meteorological Audit Standards and Equipment (Form 10-10).
- Non-Conformance/Corrective Action (NC/CA) Report documenting any test results which exceeded acceptability limits (see Section 9.2 in this document for instructions regarding NC/CA Reports).

10.2.6 <u>Relative Humidity System Performance Tests</u>

10.2.6.1 Purpose and Scope

The purpose of this procedure is to provide instruction for assessing the performance and accuracy of the relative humidity monitoring system in the field. This procedure also provides instructions for documenting and evaluating the test results.

Implementation of this procedure by an independent auditor, using equipment other than that normally utilized for routine network operation, constitutes an independent performance audit on the relative humidity measurement system. This procedure is also used for assessing the measurement system accuracy when the operational status of the relative humidity sensor is suspect, or when failure requires repair or replacement of the sensor.

10.2.6.2 Frequency

Performance audits should be conducted at least semiannually following station startup. System performance tests should be performed in conjunction with station startup and also when a problem with the sensor which might affect data accuracy is suspected or confirmed. Refer to Section 7 (Preventive and Corrective Maintenance) in Part 3 of this document for further guidance on conducting system performance tests in conjunction with corrective maintenance on the sensor.

10.2.6.3 References

- Refer to Section 10.1.3 in this document for a list of references.

10.2.6.4 Test Equipment

- Casella-London Assmann Psychrometer (or equivalent) equipped with two NIST-traceable thermometers having 0.1^{o}C resolution and a minimum accuracy of ±0.1°C of reading over a minimum range of 0°C to 35°C.
- Distilled water.
- Relative humidity look-up tables.

- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).

10.2.6.5 Procedure for Relative Humidity System Performance Test

a) Enter start of test (date, time, and initials) on Form 10-9, and in the site logbook. Indicate whether the performance test for the relative humidity measurement system is a performance audit or unscheduled system test by checking the appropriate space at the top of Form 10-9. If the performance test is not an audit, explain the reason for the test in the "Comments" section at the bottom of Form 10-9.

b) If the relative humidity sensor is mounted on a meteorological monitoring tower and the tower is folded down to gain access to the sensor, provide the proper status information to the digital data acquisition system (DAS) to indicate that the data must be excluded from the ambient monitoring data base. For stations using the Campbell Scientific CR-1000 data logger, the appropriate action is to place the system status toggle switch in the “OFF” position, indicating that the system is not collecting representative, valid data due to the maintenance or test activity to be performed.

c) Use *clean, distilled* water to saturate the wick covering the wet bulb on the reference psychrometer. (Note: Avoid touching or contaminating the wick, as this may bias the reference moisture measurement). Hold or secure the reference psychrometer adjacent to the Site relative humidity sensor and start the psychrometer aspirator fan. Allow 3 to 6 minutes for the wet and dry bulb thermometer readings to equilibrate to ambient conditions. Keep checking the psychrometer reference thermometer readings to see if they are stable (depending on prevailing conditions, obtaining a stable ambient air moisture measurement may be difficult). When the psychrometer thermometer indications are stable (don’t wait so long that the wet bulb wick dries) record the psychrometer reference thermometer readings (to the nearest tenth of a ^{o}C) in the spaces provided in the “System Test Results” section of Form 10-9.

NOTE: If ambient conditions are such that the atmospheric moisture fluctuates (indicated by varying thermometer readings), record the *lowest* readings observed simultaneously for both the wet and dry bulb thermometers.

d) Simultaneous with the reference psychrometer readings obtained in Step c), obtain and record the corresponding 1-minute block-averaged relative humidity data from the DAS (in engineering units) in the spaces provided in the “System Test Results” section of Form 10-9.

e) Use the relative humidity table to look up the reference relative humidity value, using the reference psychrometer readings and interpolating from the look up table as necessary. Record the reference relative humidity value (to the nearest tenth of a percent) in the space provided on the “System Test Results” section of Form 10-9.

f) Subtract the DAS-indicated relative humidity value (in %) obtained in Step d) above from the corresponding reference relative humidity value. Record the difference (in %) in the “Error” space provided in the “System Test Results” section of Form 10-9.

g) Repeat Steps a) through f) at a minimum of 2 additional times over the course of the audit. Calculate the arithmetic mean (average) error and record this value where indicated in the “System Test Results” section of Form 10-9.

h) **Acceptability Limit:** The data accuracy objective established for relative humidity measurement data for this monitoring program is ±10% compared to True. Evaluate the "As Found" averaged error obtained in Step g) above with respect to the acceptability criterion for measurement system accuracy.

i) If the System Performance Test average error satisfies the acceptability criteria, and no maintenance or adjustment was required or performed on the sensor following the completion of "As Found" Performance Tests (other than cleaning or replacing the sensor dust cap), then proceed to 10.2.6.6 ("System Restoration") below.

j) If the System Performance Test average error exceeds the acceptability criteria for accuracy stated above, or if any maintenance was performed which might affect the performance of the sensor (including replacement of the sensor), then repeat the System Performance Tests described in Steps a) through h) above and record these "As Left" test results in the "System Test Results" section on a separate Form 10-9. *Clearly and prominently label these test data “As Left”.*

   Evaluate all "As Left" test results by comparing the "As Left" errors with the acceptability criteria for accuracy above. If the test results satisfy the relative humidity system accuracy acceptability criteria, then proceed to 10.2.6.6 ("System Restoration") below. If any of the System test errors exceed the acceptability criteria, investigate to find the cause of the problem and establish a plan of action to promptly correct the condition. Satisfactory System Test Results must be obtained before the problem can be considered successfully resolved and valid data collection resumed.

10.2.6.6 System Restoration

a) Inspect the sensor dust cap for contamination and cleanliness. Clean and/or replace the protective dust cap on the sensor (if necessary) according to manufacturer’s specifications. (Refer to Section 7.6 in this document for relative humidity sensor maintenance procedures).

b) Remove all test equipment utilized in the performance of this procedure.

c) If the relative humidity system was performance-tested with the tower in the folded-down position, restore the meteorological tower and secure it in the upright position by reversing the procedure described in Section 7.1.1, Step 2.

d) Ensure all documentation is complete, the DAS status toggle switch is returned to the "ON" position, and that all measurement system components are functioning normally.

e) Enter the time that the relative humidity system was restored to normal operation on Form 10-9 and in the site logbook.

10.2.6.7 Documentation (Examples of all forms are presented at end of this section)

- Performance Test Data for Relative Humidity Measurement Systems (Form 10-9).
- Meteorological Audit Standards and Equipment (Form 10-10).
- Non-Conformance/Corrective Action (NC/CA) Report documenting any test results which exceeded acceptability limits.

10.2.7 <u>Barometric Pressure System Performance Test</u>

10.2.7.1 Purpose and Scope

The purpose of this procedure is to provide instruction for assessing the performance and accuracy of the barometric pressure monitoring system in the field. This procedure also provides instructions for documenting and evaluating the test results.

Implementation of this procedure by an independent auditor, using equipment other than that normally utilized for routine network operation, constitutes an independent performance audit on the relative humidity measurement system. This procedure is also used for assessing the measurement system accuracy when the operational status of the barometric sensor is suspect, or when failure requires repair or replacement of the sensor.

10.2.7.2 Frequency

Performance audits should be conducted at least semiannually following station startup. System performance tests should be performed in conjunction with station startup and also when a problem with the sensor which might affect data accuracy is suspected or confirmed. Refer to Section 7 (Preventive and Corrective Maintenance) in this document for further guidance on conducting system performance tests in conjunction with corrective maintenance on the sensor.

10.2.7.3 References

- Climatronics System Engineering Manual.

10.2.7.4 Test Equipment

- NIST-traceable digital barometer with a range of 600-1,100 mb and an accuracy of ±0.5 mb.
- Laptop PC with serial data cable (used for obtaining electronic files of the test data during or immediately subsequent to the performance test).

10.2.7.5 Instructions

a) Enter start of test (date, time, and initials) on Form 10-10 and in the site logbook. Indicate whether the performance test for the barometric pressure measurement system is a performance audit or unscheduled system calibration check by checking the appropriate space at the top of Form 10-10. If the performance test is not an audit, explain the reason for the test in the "Comments" section at the bottom of Form 10-10.

b) Hold or secure the reference barometer as close as practicable to the Site barometric pressure sensor. Turn on the reference barometer and allow 3 to 6 minutes for the barometer readings to equilibrate to ambient conditions. When the reference barometric pressure reading has stabilized, record the reference barometric pressure indication in the spaces provided in the “System Test Results” section of Form 10-10.

c) Simultaneous with the reference barometer reading obtained in Step b), obtain and record the instantaneous (or, alternatively, the 1-minute block-averaged) barometric pressure data value from the DAS (in engineering units) in the spaces provided in the “System Test Results” section of Form 10-10.

d) Subtract the reference barometric pressure value (in mb) obtained in Step b) above from the corresponding DAS barometric pressure value obtained in Step c) above. Record the difference (in mb) in the “Error” space provided in the “System Test Results” section of Form 10-10.

e) Repeat Steps b) through d) at 2 additional times over the course of the audit. Calculate the arithmetic mean (average) error and record this value where indicated in the “System Test Results” section of Form 10-10.

f) **<u>Acceptability Limit</u>:** The data accuracy objective established for barometric pressure measurement data for this monitoring program is ±3mb compared to True. Evaluate the "as found" System Performance Test Results averaged error obtained in Step e) above as compared to this accuracy criterion.

g) If the System Performance Test average error satisfies the acceptability criterion and no maintenance or adjustment was required or performed on the sensor following the completion of "as found" Performance Tests, then proceed to 10.2.7.6 ("System Restoration") below.

h) If the System Performance Test average error exceeds the acceptability criterion for accuracy stated above, or if any maintenance was performed which might affect the performance of the sensor (including replacement of the sensor), then repeat the System Performance Tests described in Steps a) through e) above and record these "As Left" test results in the "System Test Results" section on a separate Form 10-10.

Evaluate all "As Left" test results by comparing the "As Left" errors with the acceptability criteria for accuracy stated in Step above. If the test results satisfy the barometric pressure system accuracy acceptability criteria, *prominently label acceptable System Test results recorded on the second Form 10-10 "<u>As Left</u>"* and proceed to 10.2.7.6 ("System Restoration") below.

If any of the System test errors exceed the acceptability criteria, investigate to find the cause of the problem and establish a plan of action to promptly correct the condition. Satisfactory System Performance Test results must be obtained before the problem can be considered successfully resolved and valid barometric pressure data collection resumed.

10.2.7.6 System Restoration

a.) Remove all test equipment utilized in the performance of this procedure.

b.) Ensure all documentation is complete and that all measurement system components are functioning normally.

c.) Enter the time that the barometric pressure System Performance Test was completed on Form 10-10 and in the site logbook.

10.2.7.7 Documentation (examples of all forms are presented at end of this section)

- Performance Test Data for Barometric Pressure Measurement Systems (Form 10-10).
- Meteorological Audit Standards and Equipment (Form 10-11).
- Non-Conformance/Corrective Action (NC/CA) Report documenting any test results which exceeded acceptability limits. Refer to Section 9.2 in this document for instructions regarding NC/CA reports.

FORM 10-1: METEOROLOGICAL SYSTEMS AUDIT CHECKLIST (Page 1 of 2)

Network:	Audit Date:
Site:	Auditor:

GENERAL SITE CONDITIONS	**Yes**	**No**
Is the station interior neat and orderly?		
Is the structural condition of the equipment shelter acceptable?		
Is the shelter temperature regulation compatible with stable and proper instrument operation?		
Are the site grounds well maintained?		
EXPOSURE OF INSTRUMENTS	**Yes**	**No**
Are all booms rigid, level and properly aligned?		
Are wind sensors plumb, and rigidly mounted at least two tower widths away from tower?		
Is the tower in good physical condition, rigid and all tower cables secure?		
Are temperature sensors housed in aspirated radiation shields?		
Are humidity and/or dew point sensors housed in aspirated radiation shields?		
Are radiation sensors clean, level and unobstructed from the sun all year?		
Are precipitation sensors properly elevated, level, located away from any drip lines and protected with a wind break?		
OPERATIONS	**Yes**	**No**
Are all sensors operational?		
Are all signal connections clean, protected and rust free?		
Are all vanes/cups/propellers intact?		
Are wind speed and wind direction bearings replaced on schedule?		
Are all wind sensor heating jackets intact and operational?		
Are all aspirators clean and aspirator fan(s) operational?		
Is the precipitation gauge clean?		
Is D.A.S. operational and indicate proper time and date?		
Are routine site checks performed at weekly intervals?		
Are calibration checks performed as scheduled?		

FORM 10-1: METEOROLOGICAL SYSTEMS AUDIT CHECKLIST (Page 2 of 2)

Network:	Site:	Audit Date:

DOCUMENTATION AND FORMS	Yes	No
Are QA/QC objectives and procedures documented?		
Is the station logbook present?		
Are the station logs up-to-date?		
Are the station logs detailed and legible?		
Are the system calibration forms present?		
OVERALL COMMENTS	**Yes**	**No**
Overall, are the station and instruments well maintained?		
Is the site and equipment in good working order?		
Overall, is the site technician knowledgeable and following SOPs?		
Overall, are monitoring activities consistent with data quality objectives?		
Does system data agree with the current ambient conditions?		
Does the station siting conform to applicable guidelines?		

Comments:

Site Technician:______________________________ Auditor: ________________________________

QA Review:_________________________________ ***ENVIROPLAN CONSULTING***

FORM 10-2: PERFORMANCE TEST DATA FOR HORIZONTAL WIND SPEED MEASUREMENT SYSTEM

Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site:	Site Operator:
Sensor Level (AGL): Meters	Instrument Range: 0.0 mph to 100.0 mph
Location:	Time off line: Time on line:

System Component	Manufacturer	Model Number	Serial Number "As Found"	Serial Number "As Left"
Sensor	Climatronics	100075		
Data Acquisition System	Campbell Scientific	CR-1000		

WS PERFORMANCE TEST ACCEPTABILITY LIMITS (Climatronics F-460 Cup Anemometer)		
Type of Test	**"As Found"**	**"As Left"**
1. Sensor Starting Torque	< 0.2 gm-cm	Same as "As Found"
2. Overall System Error	≤ 0.6 mph (compared to True)	Same as "As Found"

SYSTEM TEST RESULTS:

STATUS	MOTOR RPM	TARGET (mph) (**A**)	DAS (mph) (**B**)	ERROR (mph) (= **B-A**)
AS FOUND	0	0.3		
	300	16.1		
	600	31.8		
	900	47.6		
AS LEFT	0	0.3		
	300	16.1		
	600	31.8		
	900	47.6		

"As Found" bearing torque check: Clockwise_____________gm-cm; Counter-clockwise__________gm-cm

Sensor bearings: Last replaced: _____________ Next due:________________

"As Left" bearing torque check: Clockwise______________gm-cm; Counter-clockwise___________gm-cm

Comments: ____

____

Technician: ______________________________ Auditor: (if applicable)_____________________________

QA Review: ______________________________

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FORM 10-3: PERFORMANCE TEST DATA FOR VERTICAL WIND SPEED MEASUREMENT SYSTEMS

Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site: Plant Met Site	Site Operator:
Sensor Level (AGL): Meters	Instrument Range: -25.0 mph to 25.0 mph
Location:	Time off line: Time on line:

System Component	**Manufacturer**	**Model Number**	**Serial Number** “As Found”	“As Left”
Sensor	Climatronics	102236		
Data Acquisition System	Campbell Scientific	CR-1000		

WS PERFORMANCE TEST ACCEPTABILITY LIMITS (Climatronics Vertical Component Anemometer)		
Type of Test	**“As Found”**	**“As Left”**
1. Sensor Starting Torque	< 0.3 gm-cm	< 0.14 gm-cm
2. Overall System Error	≤ 0.6 mph (compared to True)	Same as “As Found”

SYSTEM TEST RESULTS:

STATUS	MOTOR RPM	TARGET (mph) (**A**)	AS FOUND		AS LEFT	
			DAS (mph) (**B**)	ERROR (mph) (= **B-A**)	DAS (mph) (**C**)	ERROR (mph) (= **C-A**)
CLOCKWISE	0	0.0				
	300	4.2				
	600	8.4				
	900	12.6				
COUNTER-CLOCKWISE	0	0.0				
	300	-4.2				
	600	-8.4				
	900	-12.6				

“As Found” bearing torque check: Clockwise_____________gm-cm; Counter-clockwise__________gm-cm

Sensor bearings: Last replaced:________________________ Next due:_____________________

“As Left” bearing torque check: Clockwise______________gm-cm; Counter-clockwise___________gm-cm

Comments: ____

____

Technician: _______________________________ Auditor: (if applicable)__________________________________

QA Review: _______________________________ ***ENVIROPLAN CONSULTING***

FORM 10-4: PERFORMANCE TEST DATA FOR WIND DIRECTION MEASUREMENT SYSTEMS

Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site:	Site Operator:
Sensor Level (AGL):	Instrument Range: 0 to 360 Degrees
Location:	Time off line: Time on line:

System Component	Manufacturer	Model Number	Serial Number "As Found"	Serial Number "As Left"
Sensor	Climatronics	100076		
Data Acquisition System	Campbell Scientific	CR-1000		

WD PERFORMANCE TEST ACCEPTABILITY LIMITS		
Type of Test	**"As Found"**	**"As Left"**
1. Sensor Starting Torque	< 6 gm-cm (CW & CCW)	< 3 gm-cm (CW & CCW)
2. Sensor Orientation Error	± ≤ 2^o	± ≤ 1^o
3. Total System Azimuth Error	± ≤ 5^o	± ≤ 5^o (preferably ± ≤ 3^o)

SYSTEM TEST RESULTS:

TEST POINT (**A**)	AS FOUND DAS (**B**)	AS FOUND Sensor Error (B-A) = **C**	AS FOUND Total Error (= C-D)	AS LEFT (**E**) DAS	AS LEFT Sensor Error (A-E) = **F**	AS LEFT Total Error (= F-G)
30°						
60°						
90°						
120°						
150°						
180°						
210°						
240°						
270°						
300°						
330°						
360°						

Sensor orientation relative to true north: **(D)**_________Degrees (as found); **(G)**___________Degrees (as left)

"As found" bearing torque check: Clockwise_____________gm-cm; Counter-clockwise_____________gm-cm

Bearings last replaced:_________________________ Next Due: ____________________________________

"As left" bearing torque check: Clockwise_____________gm-cm; Counter-clockwise_____________gm-cm

Comments: Magnetic Declination of Site = ____

____

Technician:_____________________________________ Auditor: (if applicable):______________________________

QA Review: _____________________________________

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FORM 10-5: PERFORMANCE TEST DATA FOR AMBIENT TEMPERATURE MEASUREMENT SYSTEMS

Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site:	Site Operator:
Sensor Level (AGL): Meters	Instrument Range: -30.0 to +50.0 °C
Location:	Time off line: Time on line:

System Component	Manufacturer	Model Number	Serial Number "As Found"	Serial Number "As Left"
Sensor	Climatronics	100093		
Data Acquisition System	Campbell Scientific	CR-1000		

TEMPERATURE PERFORMANCE TEST ACCEPTABILITY LIMITS

Type of Test	"As Found"	"As Left"
1. Total System Error (DAS Response - Reference Temp. = Error)	Error ≤ ± 0.5° C (each test point)	Error ≤ ± 0.5° C (each test point) **(Preferably: ≤ ± 0.2° C, each test point)**

SPECIAL NOTES:

Assess system accuracy at three known temperatures (immersing the probe and reference thermometer together in stable thermal masses). Known temperatures should include an ice slurry bath, a "room temp." bath (~ 15° ~ 27° C) and a "hot" bath (75 ~ 95% of positive portion of measurement range).

Ensure probe radiation shield is clean, in good physical condition and has unobstructed air flow. If shield is actively aspirated, ensure blower fan is operating properly. Note any deficiencies in "Comments" section below.

System Test Results:

TEST POINT	"AS FOUND"				"AS LEFT"			
	Reference Temp. (°C) (**A**)	DAS (°F)	DAS (°C) (**B**)	System Error (°C) (**= B – A**)	Reference Temp. (°C) (**A**)	DAS (°F)	DAS (°C) (**B**)	System Error (°C) (**= B – A**)
Ice Bath (0.1 – 0.2°C)								
"Ambient" (15 – 25°C)								
Hot Bath (35 – 48°C)								

Comments:____

____

Technician:_______________________________ Auditor: (if applicable):_____________________

QA Review: _______________________________

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FORM 10-6: PERFORMANCE TEST DATA FOR DELTA TEMPERATURE MEASUREMENT SYSTEMS
Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site:	Site Operator:
Sensor Level (AGL): Meters	Instrument Range: -5.0 to +10.0 °C
Location:	Time off line: Time on line:

System Component	Manufacturer	Model Number	Serial Number "As Found"	Serial Number "As Left"
Sensor	Climatronics	100093		
Data Acquisition System	Campbell Scientific	CR-1000		

DELTA-TEMPERATURE PERFORMANCE TEST ACCEPTABILITY LIMITS

Type of Test	"As Found"	"As Left"
1. Total System Error (DAS Response - Designated Response Temp. = Error)	Error ≤ ± 0.1° C	Error ≤ ±0.1° C

SPECIAL NOTES: Assess system accuracy at five known temperatures as follows:

1. Immerse ambient and delta-temp probes together in three different stable thermal baths consisting of: an ice slurry bath, an "Ambient" bath (~15°-25°C) and a "hot" bath (35 – 48°C).
2. Immerse ambient and delta-temp probes separately in 2 stable thermal baths to generate known delta temps in the following ranges: -4.9 to -3°C and +7.5 to 9.9°C.

SYSTEM PERFORMANCE TEST RESULTS

"AS FOUND" (All Values in °C)					"AS LEFT" (All Values in °C)				
Ambient Reference Temp. (**A**)	Δ- T Reference Temp. (**B**)	Target Δ-T Response (**B-A) = C**	DAS Δ-T (**D**)	Δ-T Error (= **D - C**)	Ambient Reference Temp. (**A**)	Δ- T Reference Temp. (**B**)	Target Δ-T Response (**B-A) = C**	DAS Δ-T (**D**)	Δ-T Error (= **D - C**)

Comments:____
____
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Technician:_________________________________ Auditor: (if applicable):___________________________

QA Review: _________________________________ ***ENVIROPLAN CONSULTING***

FORM 10-7: PERFORMANCE TEST DATA FOR TIPPING BUCKET-TYPE PRECIPITATION SYSTEMS

Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site:	Site Operator:
Sensor Level (AGL): Meters	Sensor Transfer Function: 8.24ml = 1 tip = 0.01" of precipitation (for 8-inch diameter bucket)
Location:	Time off line: Time on line:

System Component	Manufacturer	Model Number	Serial Number
Sensor	Climatronics	100097	
Data Acquisition System	Campbell Scientific	CR-1000	

PRECIPITATION PERFORMANCE TEST ACCEPTABILITY LIMITS

Type of Test	"As Found"	"As Left"
1. Total System Error (the percent difference of the DAS-indicated and the actual equivalent).	Error ≤ ± 10%	Error ≤ ± 10%

SYSTEM PERFORMANCE TEST:

A) 1.) Total volume of water introduced (from burette) ______________ ml

2.) Rainfall equivalent of (A-1)_______________ (use mfg's. transfer function for sensor)

B) 1.) Total number of bucket tips during test ____________

2.) Rainfall equivalent of (B-1)_______________ (use mfg's. transfer function for sensor)

C) DAS rainfall indication before test _________ (eng. units); after test _____________ (eng. units)

D) Total rainfall indicated by DAS ____________ (Hourly data value, eng units)

E) Percent difference: $\frac{D - A2}{A2} \times 100 =$ ___________%

Comments: ____

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Technician:___________________________________ Auditor: (if applicable):_____________________________

QA Review: ____________________________________

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FORM 10-8: PERFORMANCE DATA FORM FOR SOLAR RADIATION MEASUREMENT SYSTEMS

Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site:	Site Operator:
Sensor Level (AGL): Meters	Instrument Range: 0.0 to 1,395 W/m^2
Location:	Time off line: Time on line:

Site System Component	Manufacturer	Model Number	Serial Number "As Found"	Serial Number "As Left"
Sensor	Eppley	8-48		
Data Acquisition System	Campbell Scientific	CR-1000		

Audit/CTS Equipment:

Component	Manufacturer	Model Number	Serial Number
Sensor	Eppley	8-48	
Data Acquisition System	Campbell Scientific	CR-1000	

SOLAR RADIATION PERFORMANCE TEST ACCEPTABILITY LIMITS

Type of Test	"As Found"	"As Left"
1. Total System **(Averaged)** Error (the arithmetic averaged error obtained from a full diurnal cycle (preferred) or several hours prior to and after peak solar radiation).	Average Error ≤ ± 5%	Average Error ≤ ± 5%

Summarized System Performance Test Results:

START Date & Time	END Date & Time	Audit CTS Average W/m^2 (A) *	Site System Average W/m^2 (B) *	Discrepancy (B-A) ÷ A * 100
				%

* **NOTE**: Hours during which either measurement system reports values that are <5% of full scale range (i.e., <70W/m^2) are **excluded** from the total average)

Comments:____

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Technician:________________________________ Auditor: (if applicable):__________________________

QA Review: ________________________________ ***ENVIROPLAN CONSULTING***

FORM 10-9: PERFORMANCE TEST DATA FOR RELATIVE HUMIDITY (RH) MEASUREMENT SYSTEMS

Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site:	Site Operator:
Sensor Level (AGL): Meters	Instrument Range: 0 to 100%
Location:	Time off line: Time on line:

Site System Component	**Manufacturer**	**Model Number**	**Serial Number** "As Found"	"As Left"
Sensor	Climatronics	102273		
Data Acquisition System	Campbell Scientific	CR-1000		

RELATIVE HUMIDITY PERFORMANCE TEST ACCEPTABILITY LIMITS

Type of Test	**"As Found"**	**"As Left"**
1. Total System **(Averaged)** Error (the arithmetic averaged error obtained from three or more discrete comparison checks).	Average Error ≤ ± 7%	Average Error ≤ ± 7%

SYSTEM PERFORMANCE TEST RESULTS

Test Time (L.S.T.)	REFERENCE PSYCHROMETER			SYSTEM READING	ERROR (%)
	Dry Bulb (°C)	Wet Bulb (°C)	Reference RH (%) (**A**)	DAS RH (%) (**B**)	**= B - A**
				Average System Error =	%

Comments: ____

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Technician:_________________________________ Auditor: (if applicable):___________________________

QA Review: _________________________________

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FORM 10-10: PERFORMANCE TEST DATA FOR BAROMETRIC PRESSURE MEASUREMENT SYSTEM

Performance Test is a: _____Audit (or) _______Calibration (check one; if calibration, explain reason below)

Network:	Test Date(s):
Site:	Site Operator:
Sensor Level (AGL): Meters	Instrument Range: 800 – 1100 mb
Location:	Time off line: Time on line:

Site System Component	Manufacturer	Model Number	Serial Number
Sensor	Climatronics	102663	
Data Acquisition System	Campbell Scientific	CR-1000	

Audit/CTS Equipment:

Component	Manufacturer	Model Number	Serial Number
Sensor			

BAROMETRIC PRESSURE PERFORMANCE TEST ACCEPTABILITY LIMITS

Type of Test	"As Found"	"As Left"
1. Total System **(Averaged)** Error (the arithmetic averaged error obtained from three or more discrete comparison checks).	Average Error ≤ ± 3mb	Average Error ≤ ± 3mb

SYSTEM PERFORMANCE TEST RESULTS

Test Time (L.S.T.)	REFERENCE BAROMETER	SYSTEM READINGS	ERROR (mb)
	Reference Barometric Pressure (mb)	DAS (mb)	
Average System Response Error =			mb

Comments:____

Technician:_____________________________ Auditor: (if applicable):_________________________

QA Review: ____

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FORM 10-11: AUDIT EQUIPMENT SUMMARY SHEET

Network:	Audit Date:
Site:	Auditor:

Audit Equipment	Manufacturer	Model	Serial Number	Cal. Date	Due Date
Digital Multimeter					
Wind Speed Motor					
Wind Direction Azimuth Test Fixture					
Crossarm Alignment Check Instrument(s)					
Torque Watch					
Psychrometer					
Air Thermometers					
Immersion Thermometer					
Immersion Thermometer					
Immersion Thermometer					
Burette					
Pressure Standard					
Radiation Standard					